COMPARATIVE STUDIES OF OXIC HORIZONS

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INTRODUCTION

General Statement of the Problem

In 1951, the Soil Survey Staff of the Soil Conservation Service, USDA, proposed the Comprehensive Soil Classification System. It was an attempt to classify soils based on the properties of soils with less emphasis on the genetic factors which were important in the Great Soil Group Classification System. This was a practical system and it seemed that it could be used effectively in the classification of soils not only in the United States, but also in many areas of the world. However, during the development of the new classification system, it became apparent that there was a need for more study in certain groups of soils. For example, as pointed out by the Soil Survey Staff (1960), more information and investigation were necessary to classify the order Oxisols. This order includes soils which have been called Latosols and Ground-Water Laterite soils and which are found only in the tropical and subtropical regions. Thus far, Oxisols from Hawaii and Puerto Rico have been investigated. There is a need to study the Oxisols from other areas of the world and to compare the properties of these soils.

For the reasons mentioned above, soils from Hawaii, Brazil, and Thailand were investigated. The two soils from Hawaii were the Molokai and the Pooku of the Low Humic Latosol and Humic

Ferruginous Latosol Great Soil Groups, respectively. The soil from Brazil, similar to the Hawaiian latosol, was the Terra Roxa Legitima. Lastly, the soils from Thailand included the Sadao soil profile and three horizons believed to be oxic horizons.

The objectives of this investigation were:

1. To determine the chemical, physical, and mineralogical properties of the oxic horizons of these soils.
2. To test the definition of the oxic horizon using the results of this investigation.
3. To modify the definition of the oxic horizon if necessary.

The results of each property were discussed and the four soil profiles from Hawaii, Brazil, and Thailand were compared. The oxic horizons of these soils were also compared.

Definition of Terms to be Used

Laterites

The word laterite first appeared in scientific literature approximately 150 years ago. Buchanan (1807) is believed to be the first to notice a ferruginous deposit of vesicular structure occurring just below the soil surface. When fresh, this deposit was cut easily into blocks. When exposed to air, these blocks hardened and became highly resistant to weathering. Maignien (1966) reported more than 2,000 references dealing with laterites. According to him, the early studies in India during the first half of the Nineteenth Century dealt with the descriptions of laterites and their mode of occurrence. Then, from the end of the Nineteenth Century, studies were carried out on the chemical and to some extent the mineralogical properties. In recent times, various instrumental methods have been used to investigate these properties. Based on these results, more knowledge on the genesis of laterites was obtained.

Although laterites have been described and investigated for many years, the word laterite has not been clearly defined. Therefore, the terms "laterite," latosol," and "ground-water laterite" will be used in this study as defined by the Soil Survey Staff (Kellogg, 1949).

"Laterite" is described as ferruginous materials which harden after drying. The four principal forms of laterites are: (1) Soft mottled clays that change irreversibly to hard pans or crusts; (2) cellular and mottled hard pans and crusts; (3) concretions or nodules in a matrix of unconsolidated materials; and (4) consolidated masses of concretions or nodules.

"Ground-water laterite" are soils having layers of doughy laterite beneath a leached horizon which is not called plinthite (Alexander and Cady, 1962).

Latosols

The term "latosol" has been proposed for all zonal soils in the tropical and equatorial regions. The dominant characteristics are (1) low silica-sesquioxides ratio in the clay fraction; (2) low base exchange capacity; (3) low content of most primary minerals; (4) low content of soluble constituents; (5) high degree of aggregate stability; and (6) perhaps some red color. Latosols are similar to the zonal soils previously called lateritic soils.

Oxic Horizon

According to the Soil Survey Staff (1967), the oxic horizon is defined as follows:

> The oxic horizon is an altered subsurface horizon at least 30 cm (12 inches) thick consisting of a mixture of hydrated oxides of iron or aluminum, or both, often amorphous, and variable amounts of 1:1 lattice clays and accessory highly insoluble minerals such as quartz sand. Its fine-earth fraction has little or no 2:1 lattice clay or primary minerals that can weather to release bases, iron or aluminum. For each 100 grams of clay that it contains, the fine earth holds 10 meq or less of cations from 1N NH_4Cl and has a cation-exchange capacity by NH_4OAc of 16 meq or less. The oxic horizon has a lower exchange capacity or smaller amounts of minerals that can weather physically or chemically than the cambic horizon. It differs from the argillic horizon in having few or no clay skins and in having either a gradual or diffuse increase in clay content with depth, or no increase. Its upper boundary is set at the least depth at which there is no water-dispersible clay. For diagnostic purposes, its lower boundary is usually set at a depth of 2 meters.

Oxisols

According to the Soil Survey Staff (1967), the Oxisols are defined as follows:

> Oxisols are mineral soils that have an oxic horizon at some depth within 2 meters (80 inches) of the

surface* or plinthite that forms a continuous phase within 30 cm (12 inches) of the mineral surface of the soil. No spodic or argillic horizon overlies the oxic horizon.

*If the epipedon is thicker than 2 m (80 inches), and is immediately underlain by an oxic horizon, the soil is grouped with the Oxisols.

Plinthite

Plinthite may be defined as follows (Soil Survey Staff, 1967):

> Plinthite is a sesquioxide rich, humus poor, highly weathered mixture of clay with quartz and other diluents, which commonly occurs as red mottles, usually in platy, polygonal or reticulate pattern; plinthite changes irreversibly to ironstone hardpans or irregular aggregates on exposure to repeated wetting and drying. The lower boundary of plinthite occurrence are usually diffuse or gradual, but they may be abrupt at the lithologic discontinuity.

REVIEW OF LITERATURE

The Classification of Laterites, Latosols, and Oxisols

Soil classification can either be synthetic or analytical (Manil, 1956). Synthetic classification systems can be divided into three main groups: (1) classification based on genetic factors (USSR system); (2) classification based on soil genetic processes (French and Portuguese systems); (3) classification based on the properties of pedogenetic processes (British and Australian systems). Analytical classification systems, on the other hand, is based mainly on morphological characteristics with a bias towards soil genetic considerations (FAO, Belgian and USA systems).

The classification systems cited by Maignien (1966) include map legends and cartographic units used by the Service Pedologique Interafrican.

Dual and Moorman (1962) grouped the major soils of South-east Asia according to the Comprehensive Soil Classification System and classified the dark red and reddish brown latosols and red yellow latosols as Oxisols. They also classified some of the grey-podzolic soils, for example, the Thai Korat series, as ground-water laterites.

In the Belgian classification system, the lateritic soils are those overlying a ferrallitic B horizon with the characteristics of an oxic horizon. The lateritic soils were classified as kaolisols and were comparable to the Oxisols. The kaolisols were divided into five sub-types according to pedoclimate: (1) hygro-kaolisols (Ustox), the kaolisols of low attitude tropical forest; (2) hydro-xero kaolisols (Ustox), low base saturation savannah kaolisols; (3) xero-kaolisols (idox, xerox), dry-savannah kaolisols with high base saturation; (4) humic kaolisols (humox), mountain belt kaolisols; and (5) hydro-kaolisols (aquox), hydromorphic kaolisols.

In South America, Camargo and Bennema (1962) grouped the laterites with soils containing a latosolic B horizon, a horizon equivalent to the oxic horizon.

In the Comprehensive Soil Classification System, not all of the soils formerly classified as laterites or latosols are Oxisols. In general, Oxisols have an oxic horizon or show the presence of plinthite.

The Nature of the Oxic Horizon

The oxic horizon is a diagnostic subsurface horizon which is found in soils of the tropical and subtropical regions. These soils are commonly found on very old stable geomorphic surfaces (at least mid-Pleistocene)--old high-level surfaces, high terraces and pediments occurring at elevations not over 1,500 to 2,000 meters. They also occur on young surfaces if the parent materials were strongly weathered before they were deposited.

According to Mohr (1944), the Oxisols are in the senile or the laterite stage. The laterite was referred to as "the bones of the dead soil." Similarly, Jackson and Sherman (1955) have described the laterite as being in the advanced stages of chemical weathering.

Field Characteristics Associated with Oxic Horizons

The oxic horizon normally underlies an umbric, ochric, histic, or perhaps a mollic epipedon, and it can be exposed only by truncation. Many investigators have called the oxic horizon the B horizon, while others have called it the C horizon.

Although the epipedon may contain 5 to 10% organic matter, the color change between the horizons may be gradual and the boundary may be diffused. It is often difficult, therefore, to differentiate the upper boundary of the oxic horizon (Soil Survey Staff, 1967). The oxic horizon, however, can be characterized in the field primarily by its structure and consistence. It may appear massive and may possess very weak, very coarse prismatic structure. It may also have weak or medium blocky structure. Fragments from the oxic horizon can be easily crushed between the fingers into fine granules which are usually very stable. The lower boundary of the oxic horizon is usually set at 2 meters if the solum is very deep.

In contrast to the argillic horizon which is found in the Ultisols and Alfisols, the oxic horizon in the Oxisols shows little or no evidence of clay movement in the profile.

Laboratory Characteristics of Oxic Horizons

The identification of the oxic horizon in the laboratory requires one or more of the following measurements (Soil Survey Staff, 1967):

Percentage of weatherable minerals in the sand fraction--The oxic horizon should contain less than 3% feldspar, glass, and ferromagnesian minerals in the 20-200μ sand, and there may be as much as 6% mica (muscovite).

Particle size distribution by pipette method using sodium hexametaphosphate or by 15-bar water retention method--It is essential to determine the clay content in order to express the cation exchange capacity of this horizon. Since there may be some difficulty in dispersing certain soils to measure the clay content, an independent measure has been recommended by the Soil Survey Staff. This was obtained by determining the 15-bar water and multiplying this result by a factor of 2.5. The higher value of the two methods was then used to express the cation exchange capacity of the clay.

The ratio of 15-bar water to the clay content (pipette method) has been used to indicate the dispersible characteristic of the soil. The ratio does not exceed 0.5 if the clay disperses. The ratio is 0.4 for most oxic horizons.

The oxic horizon should have more than 15% clay because of the low silt content, and the coarsest texture should be between loamy sands and sandy loams.

<u>Cation retention</u>--After being saturated with 1 $\underline{N}$ NH_4Cl solution, pH 5.2, and washed free of excess salt, the oxic horizon should retain the ammonium ions equal to or less than 10 meq/100 g of clay.

<u>Cation exchange capacity</u>--The cation exchange capacity (CEC) of the oxic horizon by buffered ammonium acetate is equal to or less than 16 meq/100 g of clay. This limitation excludes soils with high amounts of allophane.

<u>Thin sections</u>--Preparation of the thin sections is necessary when field investigation cannot differentiate the argillic horizon and the oxic horizon. If the features of the former are observed, the clay skin should not exceed 1% in the oxic horizon.

<u>Water-dispersible clay</u>--The distribution of water-dispersible clay in a profile can be used to locate the upper boundary of the oxic horizon. The amount should be less than 3% in the oxic horizon if this horizon does not have a net positive charge.

<u>Clay mineralogy</u>--The influence of the clay minerals appears to be important. Mineralogical analysis may indicate the presence of clay mineral or allophane which possesses properties which are not usually associated with the oxic horizons.

Significance to Soil Classification

In general, soils with oxic horizons in their natural states are considered to be unsuitable for agriculture. Weathering has progressed to such a stage that only the resistant primary minerals, hydrous oxides of iron and aluminum, and 1:1 lattice clay minerals (kaolin) remain. Bonnet (1966), however, recently found that crop production can be increased in the tropical humid soils with an oxic horizon when properly managed; for example, by irrigation.

MATERIALS AND METHODS

Soil Description

The soils used for this study were the Molokai, Pooku, Terra Roxa Legitima, Sadao, Siracha, Thamai, and Yasothon series. The following is a detailed description of each soil.

Molokai Silty Clay Loam

Location:	1.7 miles north of Farrington Highway, Kunia Road Junction and turn west 0.05 mile on dirt road. Sample site is northern road bank.
Classification:	Tropeptic Haplustox (Low Humic Latosol).
Parent Material:	Basic igneous material.
Vegetation:	Sugar cane.
Physiography:	Gentle slope, 0-2% south.
Elevation:	457.3 m (1,500 ft).
Climate:	Mean annual temperature: 22.8°C (73°F). Average January temperature: 21.7°C (71°F). Average July temperature: 25°C (77°F). Annual rainfall: 375-625 mm (15-25 inches).
Described and collected by:	L. D. Swindale, H. Ikawa, S. A. El-Swaify, C. Sangtian, and N. Yaibuathes.

Horizon	Depth	Description
Ap_1	0-30 cm (0-12 inches)	Dark reddish brown (2.5YR 3/4) silty clay loam; very weak coarse

Horizon	Depth	Description
		granular structure; slightly hard, friable, sticky and plastic; many roots; many interstitial pores; many fine black (iron-manganese) concretions; strong effervescence with hydrogen peroxide; slightly acid; clear wavy boundary.
Ap_2	30-82.5 cm (12-33 inches)	Dark red (10R 3/6) silty clay; weak coarse prismatic structure; hard friable to firm, sticky and plastic; fine common roots; many fine and fine tubular pores; common black (iron-manganese) concretions; strong effervescence with hydrogen peroxide.
B_{21}	82.5-110 cm (33-44 inches)	Dark red (10R 3/6) silty clay loam; weak to moderate blocky structure; hard friable to firm, sticky and plastic; few fine roots; few very fine black (iron-manganese) concretions; moderate effervescence with hydrogen peroxide.

Horizon	Depth	Description
B_{22}	110-130 cm (44-55 inches +)	Dark red (10R 3/6) silty clay; strong medium angular and subangular blocky structure; soft, friable compaction in place, sticky and plastic; very few fine roots; very fine pores; prominent thin patchy clay films on peds.

Pooku Silty Clay

Location:	250 feet south of highway at a point 1.1 miles southwest of Bailey Bridge at Kalihiwai, approximately 4 miles west of Kilauea, Kauai. Approximately 14 miles northwest of Lihue, Kauai.
Classification:	Typic Acrohumox (Humic Ferruginous Latosol).
Parent Material:	Believed to be weathered from residium from basic igneous rock.
Vegetation:	Pangola pasture.
Physiography:	Low windward slopes, slightly convex to southwest. Slopes, 1-2% at sample site.
Elevation:	97.5 m (320 ft).
Climate:	Mean annual temperature: 21.7°C (71°F). 2032-2331 mm (80-90 inches) of rainfall

distributed throughout the year.

Described and collected by: Williams and Foote, SCS, USDA.

Horizon	Depth	Description
Ap_1	0-37.5 cm (0-15 inches)	Dark yellowish-brown (10YR 4/4) silty clay mottled with reddish-brown (5YR 4/4) material by tillage; strong very fine subangular blocky structure; friable, sticky and plastic; many very fine and fine pores; many iron concretions that have a dense dark outer shell with softer yellowish center; abrupt smooth boundary.
Ap_2	37.5-47.5 cm (15-19 inches)	Dark yellowish-brown (10YR 4/4) silty clay mottled with reddish-brown (5YR 4/4) material by cultivation; weak fine subangular blocky structure; friable, sticky and plastic; common fine and very fine roots; many fine and common fine pores; many iron concretions similar to the first horizon; clear and smooth boundary.

Horizon	Depth	Description
B_{21}	47.5-75 cm (19-30 inches)	Dark reddish-brown (5YR 3/4) silty clay loam; weak fine subangular blocky structure; friable, sticky, plastic; common fine and very fine pores; nearly continuous pressure surfaces; few very firm non-magnetic particles that appear to be segregated iron; clear smooth boundary.
B_{22}	75-100 cm (30-40 inches)	Dark reddish-brown (5YR 3/4) silty clay; moderate fine subangular blocky structure; friable, sticky, plastic; common fine and very fine roots; common very fine and fine pores; nearly continuous pressure surfaces; few patchy cutans that have a metallic sheen; few saprolite fragments; this horizon is underlain by discontinuous iron seam containing a build up of roots; abrupt wavy boundary.
C_1	100-155 cm (40-62 inches)	Variegated dark reddish-brown (5YR 3/3), yellowish-red (5YR

Horizon	Depth	Description
		3/6), red (5YR 4/6), dusky-red (2.5YR 2/2) loam; weak coarse platy structure; friable with pockets of firm material, slightly sticky, slightly plastic; few very fine and fine roots; few very fine and fine pores; near the bottom is a pan that appears to have a fine platy structure; the thin plates appear to be hematite and gibbsite, are very firm and brittle, and are separated by a very porous material that has a sponge-like structure; above the pan is 1/2 to 2 inches of extremely porous and friable material thickly coated with a dark material which appears to be discrete sand under magnification; the bottom part next to the contact is coated with very thick cutans which appear to be clay skins.
C_2	155-225 cm + (62-90 inches)	Variegated dark reddish-brown (5YR 2/2), dark reddish-brown

Horizon	Depth	Description
		(2.5YR 3/4), dark red (2.5YR 3/6), very dark reddish-brown (10YR 3/2) loam; friable with pockets of firm material, and material with hue of 2.5YR has a moderately smeary feel, slightly sticky, slightly plastic; massive structure; there are many sheets of firm material that are thought to be made up of hematite at the top and gibbsite at the bottom; thick cutans appear like clay flows occur on the bottom of these lens.

Remarks:

While grinding the sample, weathered phenocrysts of Fe-Mg minerals as large as 1 mm were observed.

Terra Roxa Legitima

Location: Experimental Station of the Instituto Agronomico Ribeirao Preto County, State of Sao Paulo, Brazil.

Classification: (Humic Latosol).

Parent Material: Basalt.

Vegetation:	Sugar cane--present. Subtropical forest--original.
Physiography:	Undulating. Midway on a slope 1,000 m long. Slope 5-10%.
Elevation:	(?)
Climate:	Mean annual temperature: 21.5°C; 18°C in dry season and 24°C in rainy season. Annual rainfall: 1,300 mm, with 3 to 4 months of dry season from June to September; rainy season occurs from October to April.
Described and collected by:	A. Kupper and A. C. Moniz.

Horizon	Depth	Description
A_1p	0-16 cm (0-6.3 inches)	Dusky red (10R 3/3) silty clay; fine to very fine granular structure; sticky and plastic; abrupt and smooth boundary.
A_{31}	16-45 cm (6.3-17.7 inches)	Dusky red (10R 3/3) clay; moderate to strong fine subangular blocky structure; more than 50% of strongly developed aggregates are hard and 0.5 cm in diameter and 15-20% are very hard when dry; gradual to smooth boundary.

Vegetation:	Sugar cane--present. Subtropical forest--original.
Physiography:	Undulating. Midway on a long slope with about 1,000 m long. Slope 5-10%.
Elevation:	(?)
Climate:	Mean annual temperature: 21.5°C; 18°C in dry season and 24°C in rainy season. Annual rainfall: 1,300 mm, with 3 to 4 months of dry season from June to September; rainy season occurs from October to April.
Described and collected by:	A. Kupper and A. C. Moniz.

Horizon	Depth	Description
A_{1p}	0-16 cm (0-6.3 inches)	Dusky red (10R 3/3) silty clay; fine to very fine granular structure; sticky and plastic; abrupt and smooth boundary.
A_{31}	16-45 cm (6.3-17.7 inches)	Dusky red (10R 3/3) clay; moderate to strong fine subangular blocky structure; more than 50% of strongly developed aggregates are hard and 0.5 cm in diameter and 15-20% are very hard when dry; gradual to smooth boundary.

Horizon	Depth	Description
A_{32}	45-63 cm (17.7-24.8 inches)	Dusky red (10R 3/3) clay; moderate very fine subangular blocky structure; approximately 40% of the aggregates are very porous; these aggregates are less than 1 cm in diameter and are friable, few are firm to very firm; friable, very sticky, very plastic; gradual to diffuse and smooth boundary.
B_{21}	63-90 cm (24.8-35.4 inches)	Dusky red (10R 3/3) clay; massive, showing a very weak subangular blocky structure breaking rapidly to medium poorly developed, subangular blocky structure and further breaking to very fine (less than 2 mm) subangular blocky structure (the so-called "coffee powder"); 20-25% of very porous friable aggregates, most of which are less than 0.5 cm in diameter and some with diameters between 1 and 2 cm, very sticky, very plastic, gradual to diffuse and smooth boundary.

Horizon	Depth	Description
B_{22}	90-105 cm (34.5-41.3 inches)	Dusky red (10R 3/3) clay; massive, breaking readily to medium, poorly developed subangular blocky structure, and further breaking to very fine (less than 2 mm) sub-angular blocky structure ("coffee powder"); friable with 15% of friable aggregates less than 1 cm in diameter, very sticky, very plastic; gradual and wavy boundary.
IIB_3	105-160 cm (41.3-63 inches)	Dusky red (10R 3/3) clay; massive, breaking readily to medium, poorly developed subangular blocky structure further breaking to very fine (less than 2 mm) subangular blocky structure ("coffee powder"); 5% firm and dense aggregates; very friable, very sticky, very plastic; gradual and wavy boundary.
$IIIC_1$	160-216 cm (63-85 inches)	Dusky red (10R 3/3) clay; massive, breaking readily to poorly

Horizon	Depth	Description
		developed medium subangular blocky structure ("coffee powder"); 5-10% of hard aggregates, mostly 2-5 mm in diameter; very friable, very sticky, very plastic; gradual and wavy boundary.
C_2	216-250 cm (85-98.4 inches).	
C_3	250-300 cm (98.4-119.1 inches).	C_2 to C_8 sampled with an auger; no description of the horizons were recorded.
C_4	300-350 cm (118.1-137.8 inches).	
C_5	350-400 cm (137.8-157.5 inches).	
C_6	400-450 cm (157.5-177.2 inches).	
C_7	450-500 cm (177.2-196.9 inches).	
C_8	500-575 cm (196.9-226.4 inches).	

Remarks:

Much sugar cane roots up to 3 mm in thickness were seen throughout the profile, even at the depth of 216 cm. In the C_1 horizon a hole made by animals was found. In comparison to the other horizons the IIB_3 and $IIIC_1$ horizons had a higher concentration of small stones from basic rocks of about 5 mm diameter and completely altered into gibbsite and a few iron concretions. Those stones seemed to have been transported and for this reason it looks as if the parent material of the B_3 and C_1

horizons may have been transported, although they both appear to have been derived from basic rocks.

Sadao Series

Location: Amphoe Muang, Changwat Pattalung, Southern Thailand.

Classification: Haplorthox (Red Latosol).

Parent Material: Old alluvium.

Vegetation: Tall dense evergreen forest.

Physiography: Rolling high ridge, old alluvium or marine terrace, slope 2-8%.

Elevation: 50 m +.

Climate: Mean annual air temperature: 27.2°C. Annual rainfall: 2413.1 mm (96.5 inches).

Described and collected by: D. L. Gallup and S. Panichapong.

Horizon	Depth	Description
A_1	0-7 cm (0-2.8 inches)	Reddish-brown (5YR 4/4) loamy sand; weak medium and fine subangular blocky structure; soft; friable, non-sticky, non-plastic; plentiful medium and fine roots; many fine and medium pores; many pieces of charcoal; pH 5.0; clear smooth boundary.

Horizon	Depth	Description
A_3	7-19 cm (2.8-7.5 inches)	Reddish-brown (5YR 4/3) sandy loam to loamy sand; weak fine subangular blocky structure; friable, non-sticky, non-plastic; many medium and fine roots; many fine and medium tubular pores; few pieces of charcoal; pH 5.0.
B_1	19-33 cm (7.5-13 inches)	Reddish-brown (2.5YR 4/3) sandy loam; weak fine subangular blocky structure; friable, non-sticky, non-plastic; many medium and fine roots; many fine and medium and tubular pores; few pieces of charcoal; pH 5.0; gradual, smooth boundary.
B_{ox_1}	33-80 cm (13-31.5 inches)	Reddish-brown (2.5YR 4/3) sandy loam; weak fine subangular blocky structure; friable, non-sticky, non-plastic; common medium and fine roots; many fine tubular pores; few pieces of charcoal; pH 5.0; gradual, smooth boundary.

Horizon	Depth	Description
B_{ox_2}	80-150 cm + (31.5-59.1 inches)	Reddish-brown (2.5YR 4/3) heavy sandy loam; weak medium and fine subanguiar blocky structure; friable, slightly sticky, slightly plastic; common fine and medium few large roots; many medium and fine tubular pores; thin patchy clay film in pores and some vertical ped faces on termite nest, 8 cm by 2 cm, at 98-100 cm depth.

Remarks:

This Sadao Series has no A_2 horizon; in other localities a clear A_2 horizon may be seen. This soil thus appears to be a transition between an Ultisol and an Oxisol or it is an Oxisol in which a leached A_2 horizon is formed.

Siracha Series

Location: Sample was taken from a profile approximately 100 m from km 119 on Sukumvit Road, Amphoe Siracha, Changwat Chonburi, Thailand.

Classification: Ustox (Red-Yellow Latosol).

Parent Material: Material derived from mica schist.

Vegetation:	Agriculture land used for manioc and various fruit trees.
Physiography:	Rolling--incised old marine terrace adjacent to low hills. Slope 6-10% west.
Elevation:	Approximately 35 m.
Climate:	Mean annual temperature: 27.9°C. Average annual rainfall approximately 1,300 mm with pronounced dry season from November to May.
Described and collected by:	F. R. Moormann.

Horizon	Depth	Description
A_1	0-12 cm (0-4.7 inches)	Dark reddish-brown (5YR 3/4) sandy loam or loam; strong fine crumb structure; soft; very porous, low bulk density; clear, regular boundary.
A_3	12-28 cm (4.7-11 inches)	Dark-reddish-brown (2.5YR 3/4) sandy loam or loam; strong fine crumb; weak fine subangular blocky structure in spots; soft; very porous, low bulk density; gradual, regular boundary.
B_{ox}	28-120 cm + (11-47.2 inches)	Dark red (1YR 3/6) loam (?); fine angular quartz gravels

Horizon	Depth	Description
		present, very weak fine subangular blocky structure; soft; very porous with many layer holes and channels; low bulk density. (Note: When exposed, the dry B_{ox} material becomes rather hard.)

Thamai Series

Location:	Roadcut in front of Wat Bot Ploy Wan, some 50 m south of MERSPD 259 site, Amphoe Thamai, Changwat Chantaburi, Thailand.
Classification:	(Red Brown Latosol).
Parent Material:	Residium from basalt and/or volcanic ash.
Vegetation:	Abandoned land with grass and shrubs; surroundings consist of a wide variety of tropical fruits, pepper, and rubber.
Physiography:	Undulating, slightly incised basalt plateau. Slope 6% southeast.
Elevation:	Approximately 30 m.
Climate:	Mean annual temperature: 27.3°C. Annual rainfall: 2930.6 mm.
Described and Collected by:	F. R. Moormann and Santhad.

Horizon	Depth	Description
A_1	0-9 cm (0-3.5 inches)	Dark reddish-brown (5YR 3/3) clay; strong fine crumb; friable; many interstitial pores of various sizes; many roots; pH 5.5; clear smooth boundary.
B_1ox	9-60 cm (3.5-23.6 inches)	Dark reddish-brown (5YR 3/4) clay; moderate fine subangular blocky structure; very friable; low bulk density; many animal holes; many fine tubular pores; many roots; pH 5.5; clear smooth boundary.
B_2ox	60-150 cm + (23.6-59.1 inches)	Dark reddish-brown (5YR 3/4) clay; moderate fine subangular blocky structure and when dried, coarse prismatic with vertical cracks; very weak clay movement; slightly hard when dry but very friable when moist; some animal holes; many fine tubular pores; common roots; very little change with depth; pH 5.0.

Yasothon Series

Location:	Burrow pit in dry dipterocarp forest, near Khon Kaen University, Amphoe Muang, Changwat Khon Kaen, north-eastern Thailand.
Classification:	Ustox (?) (Red Yellow Latosol).
Parent Material:	Old alluvium.
Vegetation:	Yopa (_Morinda crures_), Sat, Daeng (_Xylia kerrii_), teng (shorea obtusa), Nam Khon (_Zizyphus cambodiana_), Kadon (_Careya arborea_), Mokyai, Huan Kwang.
Physiography:	Rolling high terrace. Slope 2%.
Elevation:	200-205 m.
Climate:	Annual mean temperature: 27.2°C, highest at 42.8°C and lowest at 5.7°C. Tropical monsoon, 1175 mm (47 inches) rainfall, distinct dry season from November to April.
Described and collected by:	D. L. Gallup, Avudh, and S. Kasemsan.

Horizon	Depth	Description
A_1	0-20 cm (0-7.9 inches)	Dark brown (7.5YR 3/2) sandy loam; weak fine granular structure; hard; friable, non-sticky, non-plastic; many fine roots; many fine interstitial pores; pH 7.0; clear wavy boundary.

Horizon	Depth	Description
B_1	20-27 cm (7.9-10.6 inches)	Red (2.5YR 3/2) sandy loam; massive, hard; friable, non-sticky, non-plastic; few fine and medium roots; many fine tubular pores, few medium pores; somewhat brittle, soil fractures abruptly under pressure; few black spots of charcoal; gradual smooth boundary.
Box_2	27-49 cm (10.6-19.3 inches)	Red (2.5YR 4/6) sandy clay loam; massive; very hard; friable, slightly sticky, slightly plastic; plentiful fine and medium roots; many fine and few medium pores, vertical crack about 75 cm in length; somewhat brittle, soil fractures under pressure; gradual smooth boundary.
Box_2	49-270 cm (19.3-106.3 inches)	Red (2.5YR 4/8) sandy clay loam; weak medium subangular blocky structure; slightly hard; friable; slightly sticky, slightly plastic; plentiful fine, few medium roots; many fine, few tubular pores;

Horizon	Depth	Description
		abrupt smooth boundary.
II and laterite	270-500 cm (106.3-196.9 inches)	Pale brown (10YR 6/3) and laterite mottle dark yellowish-brown (10YR 4/6); quartzite, sandstone and shale gravel imbedded in laterite; upper part very hard and strongly cemented, lower part moderately cemented.

Sample Preparation

After air-drying, the sample was gently crushed with a wooden roller and passed through a 2-mm sieve. The sample was thoroughly mixed and subsampled. One portion was ground to pass through a 20-mesh sieve for the determination of cation exchange capacity. Another portion of the subsample was ground to pass through a 100-mesh sieve, thoroughly mixed, and stored in a small glass vial for differential thermal and x-ray diffraction analyses and for the determination of organic matter and free iron oxide.

Methods of Analyses

Analytical methods described by the Soil Survey Staff (1960) and others were used to identify or characterize the oxic horizon.

Chemical Properties

Cation retention--Cation retention was determined after saturating the soil overnight with 1.0 *N* ammonium chloride solution and washing out the excess salt with methanol. The ammonium ions at the exchange sites were replaced with sodium ions using a solution of acidified sodium chloride (Peech *et al.*, 1947). The replaced ammonium ions were distilled with 1:1 sodium hydroxide solution and the evolved ammonia was collected in 4 percent boric acid. This acid solution was then titrated against standard sulfuric acid using a mixed indicator of methyl red and methylene blue.

Cation exchange capacity and exchangeable bases--The air-dried 20-mesh soil was saturated overnight with 1.0 *N* ammonium acetate solution buffered to pH 7. After filtering the soil suspension through the Buchner funnel, the cation exchange capacity (CEC) of the soil was determined by the procedure used for the determination of cation retention. The filtrate was used to determine the exchangeable bases Na, K, Ca, and Mg. Sodium and K were determined by means of the Beckman DU Spectrophotometer, while Ca and Mg were determined by means of the Perkin-Elmer, Model 303, Atomic Absorption Unit.

Soil pH--Soil pH was determined both in water (1:1 and 1:5) and in 1 *N* KCl solution (1:1) with a Beckman Expandomatic pH meter. The suspension was kept overnight at constant room temperature and stirred occasionally and the pH was taken after stirring. Delta pH (ΔpH), the difference between pH in KCl (1:1) and pH in H_2O (1:1), was also calculated (Soil Survey Staff, 1960).

Organic matter--Air-dried 100-mesh soil was used for determination of organic matter content. The organic matter was oxidized with dichromate and the excess dichromate was titrated with standard ferrous sulfate solution (Walkley and Black, 1943). Organic carbon content was estimated by using a recovery factor of 77 percent and organic matter content was obtained by multiplying the organic carbon content by a factor of 1.724.

Free iron oxide--The dithionite extractable iron oxide method of Kilmer (1960) was used to determine the free iron oxide content. Due to the high percentage of free iron oxide in Hawaiian soils, the size of the sample was reduced as suggested by Mr. R. T. Watanabe (personal communication, 1968).

Potassium chloride extractable aluminum--Aluminum was extracted from the soil by the method of Chapman and Pratt (1961). The aluminum content was determined colorimetrically by the aluminon method described by Hsu (1963). The procedure was modified by adjusting the solution to pH 1.5, to ensure that the final solution had a pH below 4. It was then heated at 90°C for 30 minutes in the absence of the buffer solution before the color was read on the Bausch & Lombe Colorimeter at a wavelength of 530 mμ.

Physical Properties

Particle size distribution--Particle size distribution was determined by the pipette method described by Kilmer and Alexander (1949), using sodium hexametaphosphate solution (Calgon) as the dispersing agent. After 16 hours of mechanical shaking, the sand fraction was determined as that retained over a 300-mesh sieve, while the clay fraction was determined on an aliquot pipetted off from a certain depth of the suspension after a given period of time. The silt fraction was obtained by subtracting the sand and clay percentages from 100 percent.

Water-dispersible clay--The procedure to determine water-dispersible clay was the same as that described for particle distribution. No dispersing agent, however, was used. The sand and silt fraction data, furthermore, were not recorded.

Water held at 15-bar suction--The 15-bar water retention was measured using a pressure plate apparatus (U. S. Salinity Laboratory Staff, 1954). The soil samples were saturated with water and allowed to stand overnight after packing them in rubber rings in the pressure plates. Then they were placed under 15-bar pressure until equilibrium was reached. The water retained at 15-bar was determined by removing the soils from the plates and weighing the samples before and after oven-drying overnight at 110°C.

Mineralogical Properties

Differential thermal analysis (DTA)--The Stone Automatic DTA apparatus was used. Air-dried 100-mesh whole soil was kept for at least two days in a desiccator maintained at an atmosphere of 57% relative humidity. Then a 0.1 g-sample, thoroughly mixed with 0.1 g calcined alumina, was analyzed. Nitrogen gas was passed through the sample to suppress the oxidation of organic matter and calcined alumina was used as a reference sample. This analysis was determined primarily to detect the amounts of gibbsite and kaolin.

X-ray diffraction analysis--The procedure described by Jackson (1956) was used to determine the mineralogical composition. Flocculents such as soluble electrolytes and exchangeable polyvalent metallic cations, and cementing agents such as gypsum, calcium carbonates, organic matter, hematite, goethite, colloidal silica and/or alumina, and MnO_2 were removed to obtain effective dispersion and fractionation. Sodium acetate solution buffered to pH 5.0 was used to remove the soluble salts, exchangeable polyvalent cations, and calcium and magnesium carbonates. Hydrogen peroxide was used to destroy organic matter and to remove manganese dioxide. The free iron oxides were then removed by the sodium dithionite-citrate bicarbonate method. Finally, the soil was dispersed in 2% sodium carbonate solution. The sand fraction was separated by wet sieving using a 325-mesh sieve. The silt (2-50u) and clay (<2u) fractions were separated by sedimentation and centrifugation techniques.

The sand and silt fractions were dried and ground separately and x-ray diffraction patterns of the randomly oriented powder were obtained by means of the Norelco X-ray unit using Cu radiation filtered with Ni.

An aliquot of the clay suspension was saturated with 1.0 N potassium chloride solution. About 20-30 mg of this clay were dried at room temperature on a glass slide. The preferentially oriented K-saturated clay slide was x-rayed before and after heating at 110°C, 350°C, and 500°C. Another aliquot of the clay sample was saturated with 1.0 N magnesium chloride solution and dried on a glass slide. The preferentially oriented Mg-saturated clay slide was x-rayed before and after glycolation treatment which consisted of keeping the slide overnight in an ethylene glycol atmosphere at 70°C.

RESULTS AND DISCUSSION

The results are presented in 25 tables. For ease of comparison, every table is identified by two symbols. The first is a Roman numeral which indicates the name of the soil and the second is a lower-case letter which indicates the soil property. Roman numerals I, II, III, and IV thus indicate the Molokai, Pooku, Terra Roxa Legitima, and Sadao soils, respectively. Roman numeral V is the table for the oxic horizons of these soils and the three soils from Thailand, the Siracha, the Thamai, and the Yasothon soils. Lower-case letters a and b identify the chemical and physical properties. Mineralogical properties are identified by lower-case letters, c and d. The letter c indicates the interpretations of differential thermal analysis and the letter d shows the mineralogical interpretations of x-ray diffraction analysis. The lower-case letter e indicates the calculated variables.

The location of the oxic horizon was determined by analyzing the laboratory data in view of specifications presented earlier.

The oxic horizon occurs in the Molokai soil at a depth from 82.5 to 130 cm+, while that of the Pooku soil is from 47.5 to 75 cm, which is slightly less than 30 cm. The oxic horizon of the Terra Roxa Legitima occurs at a depth from 90 to 216 cm while that of the Sadao soil is from 80 to 150 cm+. The oxic horizons of the Siracha, Thamai, and Yasothon soils are probably taken from the B horizons. The Siracha sample probably does not represent a true oxic horizon. Although Siracha is classified as an Oxisol, the true upper boundary of the oxic horizon may actually be lower than that described. Laboratory data for the Siracha horizon do not satisfy all the criteria for an oxic horizon. The Yasothon horizon studied here also does not seem to be a true oxic horizon. However, both the Siracha and Yasothon soils are entered into the discussion whenever mineralogy property is studied.

Table Ia. Some Chemical Properties of Molokai Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g soil	CEC (NH_4OAc pH 7) meq/100g soil	Exchangeable Bases meq/100g soil Na	K	Ca	Mg	Base Saturation %
Ap_1	0 - 30	11.67	14.38	0.53	0.37	4.05	1.92	47.8
Ap_2	30 - 82.5	6.06	9.51	0.38	t	1.80	1.04	33.9
B_{21}	82.5-110	6.72	7.75	0.34	0.04	1.55	1.04	37.8
B_{22}	110 -130	6.99	7.32	0.64	0.38	1.35	0.97	45.6

t = trace

Table Ia. Some Chemical Properties of Molokai Soil (Continued)

Horizon	Depth	KCl Extractable Al meq/100g soil	pH H_2O 1:5	1:1	pH KCl 1:1	Fe %	Free Iron Oxides (Fe_2O_3) %	Organic Carbon %	Organic Matter %
Ap_1	0 - 30	0.12	6.4	6.11	5.47	12.7	18.2	1.91	3.29
Ap_2	30 - 82.5	0.03	6.4	5.95	5.60	13.8	19.8	0.85	1.47
B_{21}	82.5-110	0.11	6.65	6.15	6.00	15.2	21.7	0.40	0.69
B_{22}	110 -130	0.09	6.90	6.72	6.32	15.6	22.3	0.52	0.90

Table Ib. Some Physical Properties of Molokai Soil

Horizon	Depth cm	Water Dispersible Clay %	15-Bar Water Retention %	Particle Size Distribution %Sand	%Silt	%Clay
Ap_1	0 - 30	29.7	20.8	38.4	22.4	36.4
Ap_2	30 - 82.5	17.6	19.9	23.0	15.8	52.2
B_{21}	82.5-110	6.5	20.4	16.7	43.3	40.0
B_{22}	110 -130	5.8	21.7	38.0	17.8	44.3

Table Ic. Differential Thermal Analysis Data of Molokai Soil

Horizon	Depth cm	Low Temperature Endothermic Water	Kaolin	Gibbsite	Quartz
Ap_1	0 - 30	w	m	m	-
Ap_2	30 - 82.5	w	m	m	-
B_{21}	82.5-110	w	m	w	-
B_{22}	110 -130	w	m	w	-

w = weak Low Temperature Endothermic Water about 100°C
m = moderate

Table Id. X-ray Diffraction Analysis Data of Molokai Soil

Horizon	Depth cm	Size Fraction u	Q	Gb	G	Ma	He	A	K	Mi
Ap_1	0 - 30	>50	vw	vw	-	vw	-	-	vw	-
		2-50	vw	w	-	w	w	-	w	-
		<2	-	w	-	-	-	-	m	vw
Ap_2	30 - 82.5	>50	vw	vw	-	vw	-	-	vw	-
		2-50	-	w	-	w	w	-	w	-
		<2	-	w	-	-	-	-	m	vw
B_{21}	82.5-110	>50	-	-	-	-	-	-	vw	-
		2-50	-	-	-	w	w	-	w	-
		<2	vw	vw	-	-	-	-	m	-
B_{22}	110 -130	>50	-	-	-	-	-	-	vw	-
		2-50	-	-	-	w	m	-	w	-
		<2	-	-	-	-	-	-	m	-

s = strong
m = moderate
w = weak
w(b) = weak broad
vw = very weak
vw(b) = very weak (broad)
- = none, not detected

Q = Quartz
Gb = Gibbsite
G = Goethite
Ma = Magnetite
He = Hematite
A = Anatase
K = Kaolin
Mi = Mica

Table Ie. Some Properties of Molokai Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g clay	CEC (NH_4OAc pH 7) meq/100g clay	Bases + KCl Extractable Al meq/100g clay	pH ($pH_{KCl}-pH_{H_2O}$)
Ap_1	0 - 30	22.4	27.6	13.4	-0.64
Ap_2	30 - 82.5	11.6	18.2	6.22	-0.35
B_{21}	82.5-110	13.2	15.2	5.96	-0.15
B_{22}	110 -130	12.9	13.5	6.32	-0.40

Table Ie. Some Properties of Molokai Soil (Continued)

Horizon	Depth cm	% Clay (2.5 X 15-bar water)	% 15-Bar Water/% Clay
Ap_1	0 - 30	52.0	0.57
Ap_2	30 - 82.5	49.8	0.38
B_{21}	82.5-110	51.0	0.51
B_{22}	110 -130	54.3	0.49

Table IIa. Some Chemical Properties of Pooku Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g soil	CEC (NH_4OAc pH 7) meq/100g soil	Exchangeable Bases meq/100g soil Na	K	Ca	Mg	Base Saturation %
Ap_1	0 - 37.5	7.75	18.86	0.14	0	0.20	t	1.8
Ap_2	37.5- 47.5	12.10	20.30	0.09	0.07	0.43	t	2.9
B_{21}	47.5- 75	6.01	13.59	0.07	t	0.10	t	1.3
B_{22}	75 -100	4.71	9.81	0 07	t	0.10	t	2.8
C_1	100 -155	4.20	6.20	0.11	0	0.10	t	3.4
C_2	155 -225	1.82	4.23	0.14	t	0.20	t	8.0

t = trace

Table IIa. Some Chemical Properties of Pooku Soil (Continued)

Horizon	Depth cm	KCl Extractable Al meq/100g soil	pH H_2O 1:5	pH H_2O 1:1	pH KCl 1:1	Free Iron Oxides* (Fe_2O_3) %	Organic Carbon %	Organic Matter %
Ap_1	0 - 37.5	0.05	5.15	4.80	4.75	24.5	2.36	4.07
Ap_2	37.5- 47.5	0.05	4.50	4.22	4 29	32.5	4.54	7.83
B_{21}	47.5- 75	0.04	5.50	5.10	5.35	26.2	1.64	2.83
B_{22}	75 -100	0.01	5.60	5.25	5.57	26.1	1.18	2.03
C_1	100 -155	0.10	5.43	5.40	5.65	23.5	0.88	1.52
C_2	155 -225	0.06	5.40	5.45	5.69	20 5	0.31	0.53

*Data from SCS, USDA.

Table IIb. Some Physical Properties of Pooku Soil

Horizon	Depth cm	Water Dispersible Clay %	15-Bar Water Retention* %	Particle Size Distribution %Sand	%Silt	%Clay
Ap_1	0 - 37.5	6.6	30.2	66.8	16.9	16.3
Ap_2	37 5- 47.5	21.9	31.8	52.8	37.9	9.3
B_{21}	47.5- 75	2.9	31.7	80.0	3.9	17.1
B_{22}	75 -100	13.1	30.2	80.1	7.3	12.6
C_1	100 -155	14.0	25.2	74.9	8.7	16.6
C_2	155 -225	14.3	18.3	61.0	18.5	20.5

*Data from SCS, USDA.

Table IIc. Differential Thermal Analysis of Pooku Soil

Horizon	Depth cm	Low Temperature Endothermic Water	Kaolin	Gibbsite	Quartz
Ap_1	0 - 37.5	m	-	s	-
Ap_2	37.5- 47.5	m	-	s	-
B_{21}	47.5- 75	m	-	s	-
B_{22}	75 -100	w	-	vs	-
C_1	100 -155	w	-	vs	-
C_2	155 -225	w	-	vs	-

w = weak
m = moderate
s = strong
vs = very strong

Table IId. X-ray Diffraction Analysis of Pooku Soil

Horizon	Depth cm	Size Fraction u	Q	Gb	G	Ma	He	A	K	Mi
Ap_1	0 - 37.5	>50	-	m	m	-	vw	-	-	-
		2-50	s	vw	vw	vw	vw	-	-	-
		<2	w	w	-	-	-	m	-	-
Ap_2	37.5- 47.5	>50	-	w	m	-	vw	-	-	-
		2-50	w	vs	vw	vw	vw	-	-	-
		<2	s	s	-	-	-	m	-	-
B_{21}	47.5- 75	>50	-	s	vw	-	vw	-	-	-
		2-50	-	vw	vw	vw	-	-	-	-
		<2	-	s	-	-	-	vw	-	-
B_{22}	75 -100	>50	-	s	vw	-	vw	-	-	-
		2-50	-	vw	vw	vw	vw	-	-	-
		<2	-	s	-	-	-	w	-	-
C_1	100 -155	>50	-	vs	vw	-	vw	-	-	-
		2-50	-	vs	vw	vw	vw	-	-	-
		<2	-	m	-	-	-	w	-	-
C_2	155 -225	>50	-	vs	vw	-	vw	-	-	-
		2-50	-	vs	vw	vw	vw	-	-	-
		<2	-	s	-	-	-	vw	-	-

s = strong
m = moderate
w = weak
w(b) = weak (broad)
vw = very weak
vw(b) = very weak (broad)
- = none; not detected

Q = Quartz
Gb = Gibbsite
G = Goethite
Ma = Magnetite
He = Hematite
A = Anatase
K = Kaolin
Mi = Mica

Table IIe. Other Properties of Pooku Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g clay	CEC (NH_4OAc pH 7) meq/100g clay	Bases + KCl Extractable Al meq/100g clay	pH ($pH_{KCl}-pH_{H_2O}$)
Ap_1	0 - 37 5	10.3	25.0	0 52	-0.05
Ap_2	37.5- 47.5	16.0	25.5	0 81	-0.07
B_{21}	47.5- 75	7.6	17.1	0.26	+0.25
B_{22}	75 -100	6.2	13.0	0.23	+0.32
C_1	100 -155	6 7	9.8	0.49	+0.15
C_2	155 -225	4.0	9.2	0.87	+0.24

Table IIe. Other Properties of Pooku Soil (Continued)

Horizon	Depth cm	% Clay (2.5 X 15-bar water)	% 15-Bar Water/% Clay
Ap_1	0 - 37.5	75.5	1.85
Ap_2	37.5- 47.5	79.5	3.41
B_{21}	47.5- 75	79.3	1.85
B_{22}	75 -100	75.5	2.40
C_1	100 -155	63.0	1.52
C_2	155 -225	45.6	0.89

Table IIIa. Some Chemical Properties of Terra Roxa Legitima

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g soil	CEC (NH_4OAc pH 7) meq/100g soil	Exchangeable Bases meq/100g soil Na	K	Ca	Mg	Base Saturation %
A_{1p}	0- 16	8.38	12.25	0.14	0.33	0.22	0.53	10.0
A_{31}	16- 45	7.30	10.69	0.14	t	0.20	0.44	7.3
A_{32}	45- 63	4 15	7.89	0.11	0.02	0.10	0.25	6.2
B_{21}	63- 90	4.56	6.84	0.07	t	0.16	0.22	6.6
B_{22}	90-105	3.89	6.98	0.11	t	0.14	0.16	5.9
IIB_3	105-160	3.29	5.91	0.11	t	0.12	0.15	6.4
$IIIC_1$	160-216	2.97	5.31	0.09	t	0.09	0.15	6.2
C_3	250-300	2.98	4.16	0.09	0.02	0.10	0.05	6.5
C_5	350-400	2 71	4.22	0.09	0	0.30	0.05	10.4
C_8	450-500	2.47	4.50	0 09	0.04	0.10	0.05	6.2
C_9	500-575	2.41	5.80	0.09	0.09	0.10	0.05	5.7

t = trace

Table IIIa. Some Chemical Properties of Terra Roxa Legitima (Continued)

Horizon	Depth cm	KCl Extractable Al meq/100g soil	pH H_2O 1:5	pH H_2O 1:1	pH KCl 1:1	Free Iron Oxides (Fe_2O_3) %	Organic Carbon %	Organic Matter %
$A_{1}p$	0- 16	0.03	5.65	5.40	4.92	23.2	2.32	4.00
A_{31}	16- 45	0.03	5.95	5.57	5.13	23.0	1.99	3.43
A_{32}	45- 63	0.04	6.20	6.07	5.10	23.7	0.92	1.59
B_{21}	63- 90	0.03	6.65	6.20	5.57	23.6	0.83	1.43
B_{22}	90-105	0.04	7.10	6.47	6.01	24.5	0.78	1.34
IIB_3	105-160	0.10	6.65	6.56	6.22	23.8	0.68	1.17
$IIIC_3$	160-216	t	6.85	6.57	6.31	24.9	0.58	1.00
C_3	250-300	0.05	6.20	5.85	5.81	26.9	0.36	0.62
C_5	350-400	0.04	5.95	5.30	5.40	24.1	0.38	0.66
C_8	450-500	0.04	6.40	5.95	6.02	24.9	0.21	0.48
C_9	500-575	0.11	5.95	5.90	5.81	25.7	0.21	0.36

Table IIIb. Some Physical Properties of Terra Roxa Legitima

Horizon	Depth cm	Water Dispersible Clay %	15-Bar Water Retention %	Particle Size Distribution %Sand	%Silt	%Clay
$A_{1}p$	0- 16	30.7	19.8	30.0	22.7	47.3
A_{31}	16- 45	40.8	20.6	29.9	17.2	53.0
A_{32}	45- 63	48.6	22.9	22.6	16.8	60.6
B_{21}	63- 90	22.0	22.9	20.7	28.5	51.9
B_{22}	90-105	7.5	22.5	16.6	11.7	71.7
IIB_{3}	105-160	5.2	23.4	28.4	39.2	32.4
$IIIC_{1}$	160-216	4.9	23.53	24.7	4.5	71.2
C_{3}	250-300	45.8	23.9	18.9	21.6	59.6
C_{5}	350-400	52.4	24.0	24.7	33.0	42.3
C_{8}	450-500	45.2	23.8	35.6	21.8	42.6
C_{9}	500-575	20.9	24.0	43.8	14.1	42.2

Table IIIc. Differential Thermal Analysis of Terra Roxa Legitima

Horizon	Depth cm	Low Temperature Endothermic Water	Kaolin	Gibbsite	Quartz
$A_{1}p$	0- 16	w	w	s	-
A_{31}	16- 45	w	w	s	-
A_{32}	45- 63	w	w	s	-
B_{21}	63- 90	w	w	s	-
B_{22}	90-105	w	w	s	-
IIB_{3}	105-160	w	w	s	-
$IIIC_{1}$	160-216	w	w	s	-
C_{3}	250-300	w	w	s	-
C_{5}	350-400	w	w	s	-
C_{8}	450-500	w	w	s	-
C_{9}	500-575	w	w	s	-

w = weak
s = strong

Table IIId. X-ray Diffraction Analysis of Terra Roxa Legitima

Horizon	Depth cm	Size Fraction μ	Q	Gb	G	Ma	He	A	K	Mi
A_{1p}	0- 16	>50	s	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	vw	-	-	-	-	w	-
A_{31}	16- 45	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
A_{32}	45- 63	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
B_{21}	63- 90	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
B_{22}	90-105	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
IIB_3	105-160	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
$IIIC_1$	160-216	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-

Table IIId. X-ray Diffraction Analysis of Terra Roxa Legitima (Continued)

Horizon	Depth cm	Size Fraction u	Q	Gb	G	Ma	He	A	K	Mi
		<2	-	m	-	-	-	-	m	-
C_3	250-300	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	m	-	-	-	-	m	-
C_5	350-400	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	vw	-	-	-	-	s	-
C_8	450-500	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	vw	-	-	-	-	w	-
C_9	500-575	>50	vs	w	-	-	vw	-	vw	-
		2-50	vs	vs	-	-	w	-	vw	-
		<2	-	vw	-	-	-	-	w	-

s = strong
m = moderate
w = weak
w(b) = weak (broad)
vw = very weak
vw(b) = very weak (broad
- = none; not detected

Q = Quartz
Gb = Gibbsite
G = Goethite
Ma = Magnetite
He = Hematite
A = Anatase
K = Kaolin
Mi = Mica

Table IIIe. Some Properties of Terra Roxa Legitima

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g clay	CEC (NH_4OAc pH 7) meq/100g clay	Bases + KCl Extractable Al meq/100g clay	pH ($pH_{KCl}-pH_{H_2O}$)
A_1p	0- 16	16.9	24.7	2.52	-0.52
A_{31}	16- 45	13.8	20.2	1.53	-0.44
A_{32}	45- 63	6.8	13.0	0.87	-0.97
B_{21}	63- 90	8.0	11.9	0.83	-0.63
B_{22}	90-105	5.4	9.7	0.63	-0.46
IIB_3	105-160	5.6	10.1	0.82	-0.35
$IIIC_1$	160-216	4.2	7.5	0.46	-0.24
C_3	250-300	5.1	7.1	0.54	-0.04
C_5	350-400	4.5	7.1	0.83	+0.10
C_8	450-500	4.1	7.5	0.71	+0.07
C_9	500-575	4.1	9.7	0.73	-0.09

Table IIIe. Some Properties of Terra Roxa Legitima (Continued)

Horizon	Depth cm	% Clay (2.5 X 15-bar water)	% 15-Bar Water/% Clay
A_{1p}	0- 16	49.5	0.42
A_{31}	16- 45	51.6	0.39
A_{32}	45- 63	57.3	0.38
B_{21}	63- 90	57.3	0.44
B_{22}	90-105	56.3	0.31
IIB_{3}	105-160	58.5	0.72
$IIIC_{1}$	160-216	58.8	0.33
C_{3}	250-300	59.8	0.40
C_{5}	350-400	60.0	0.57
C_{8}	450-500	59.5	0.56
C_{9}	500-575	60.0	0.57

Table IVa. Some Chemical Properties of Sadao Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g soil	CEC (NH_4OAc pH 7) meq/100g soil	Exchangeable Bases meq/100g soil				Base Saturation %
				Na	K	Ca	Mg	
A_1	0- 7	1.35	2.25	0.07	0.03	0.20	0.05	24.4
A_3	7- 19	0.94	2.13	0.09	0.03	0.10	t	10.3
B_1	19- 33	0.98	1.85	0.07	0	0.10	t	9.2
B_{ox_1}	33- 80	0.94	1.42	0.07	t	0.10	t	12.0
B_{ox_2}	80-100	1.32	1.47	0.11	t	0.10	t	14.3

t = trace

Table IVa. Some Chemical Properties of Sadao Soil (Continued)

Horizon	Depth cm	KCl Extractable Al meq/100g soil	pH H_2O		pH KCl	Free Iron Oxides (Fe_2O_3) %	Organic Carbon %	Organic Matter %
			1:5	1:1	1:1			
A_1	0- 7	0.07	5.0	4.55	4.05	1.0	0.98	1.69
A_3	7- 19	0.09	4.95	4.35	4.00	1.0	0.67	1.25
B_1	19- 33	0.07	4.95	4.42	4.14	1.3	0.41	0.71
B_{ox_1}	33- 80	0.07	5.15	4.12	4.10	1.2	0.27	0.47
B_{ox_2}	80-150	0.11	5.25	4.10	4.05	2.0	0.78	1.34

Table IVb. Some Physical Properties of Sadao Soil

Horizon	Depth cm	Water Dispersible Clay %	15-Bar Water Retention %	Particle Size Distribution %Sand	%Silt	%Clay
A_1	0- 7	6.0	5.4	82.5	1.8	15.7
A_3	7- 19	8.8	4.1	79.0	6.2	15.7
B_1	19- 33	12.9	4.8	78.3	6.1	15.7
Box_1	33- 80	19.7	5.1	77.4	9.0	11.6
Box_2	80-150+	4.7	6.2	74.5	6.2	19.3

Table IVc. Differential Thermal Analysis of Sadao Soil

Horizon	Depth cm	Low Temperature Endothermic Water	Kaolin	Gibbsite	Quartz
A_1	0- 7	-	vw	vw	m
A_3	7- 19	-	vw	vw	m
B_1	19- 33	vw	vw	vw	m
Box_1	33- 80	-	vw	vw	m
Box_2	80-150	-	vw	vw	m

vw = very weak
m = moderate

Table IVd. X-ray Diffraction Analysis of Sadao Soil

Horizon	Depth cm	Size Fraction μ	Q	Gb	G	Ma	He	A	K	Mi
A_1	0- 7	>50	vs	-	-	-	-	-	w(b)	-
		2-50	vs	-	-	-	-	-	w(b)	-
		<2	w	-	-	-	-	-	vs	vw
A_3	7- 19	>50	vs	-	-	-	-	-	w(b)	-
		2-50	vs	-	-	-	-	-	w(b)	-
		<2	w	-	-	-	-	-	vs	vw
B_1	19- 33	>50	vs	-	-	-	-	-	w(b)	-
		2-50	vs	-	-	-	-	-	w(b)	-
		<2	w	-	-	-	-	-	vs	vw
Box_1	33- 80	>50	vs	-	-	-	-	-	w(b)	-
		2-50	vs	-	-	-	-	-	w(b)	-
		<2	w	-	-	-	-	-	vs	vw
Box_2	80-150+	>50	vs	-	-	-	-	-	w(b)	-
		2-50	vs	-	-	-	-	-	w(b)	-
		<2	w	-	-	-	-	-	vs	vw

s = strong
m = moderate
w = weak
w(b) = weak (broad)
vw = very weak
vw(b) = very weak (broad)
- = none; not detected

Q = Quartz
Gb = Gibbsite
G = Goethite
Ma = Magnetite
He = Hematite
A = Anatase
K = Kaolin
Mi = Mica

Table IVe. Other Properties of Sadao Soil

Horizon	Depth cm	Cation Retention (NH_4Cl) meq/100g clay	CEC (NH_4OAc pH 7) meq/100g clay	Bases + KCl Extractable Al meq/100g clay	pH (pH_{KCl}-pH_{H_2O})
A_1	0- 7	8.6	14.3	2.67	-0.50
A_3	7- 19	6.0	13.6	1.97	-0.35
B_1	19- 33	6.2	11.9	1.52	-0.28
Box_1	33- 80	7.3	11.1	1.88	-0.02
Box_2	80-150	6.8	7.6	1.66	-0.35

Table IVe. Other Properties of Sadao Soil (Continued)

Horizon	Depth cm	% Clay (2.5 X 15-bar water)	% 15-Bar Water/% Clay
A_1	0- 7	13.5	0.34
A_3	7- 19	10.3	0.26
B_1	19- 33	12.0	0.31
Box_1	33- 80	12.8	0.44
Box_2	80-150	15.5	0.32

Table Va. Some Chemical Properties of the Oxic Horizons

Soil	Depth cm	Cation Retention (NH_4Cl) meq/100g soil	CEC (NH_4OAc pH 7) meq/100g soil	Exchangeable Bases meq/100g soil				Base Saturation %
				Na	K	Ca	Mg	
Molokai	82.5-110	7.75	6.72	0.34	0.04	1.55	1.04	37.8
	110 -130	7.32	6.99	0.64	0.38	1.35	0.97	45.6
Pooku	47.5- 75	6.01	13.59	0.07	t	0.10	t	1.3
Terra Roxa Legitima	90 -105	3.89	6.98	0.11	t	0.14	0.16	5.9
	105 -160	3.29	5.91	0.11	t	0.12	0.15	6.2
	160 -216	2.97	5.31	0.09	t	0.09	0.15	6.2
Sadao	80 -150	1.32	1.47	0.11	t	0.10	t	14.3
Siracha	28 -120	7.16	9.56	0.20	0.38	2.90	0.91	45.9
Thamai	80 -100	8.16	9.83	0.07	0	0.10	0.36	5.6
Yasothon	49 -500	1.56	2.17	0.07	0.03	0.30	t	6.0

t = trace

Table Va. Some Chemical Properties of the Oxic Horizons (Continued)

Soil	Depth cm	KCl Extractable Al meq/100g soil	pH H_2O 1:5	pH H_2O 1:1	pH KCl 1:1	Free Iron Oxides (Fe_2O_3) %	Organic Carbon %	Organic Matter %
Molokai	82.5-110	0.11	6.65	6.15	6.00	21.7	0.40	0.69
	110 -130	0.09	6.90	6.72	6.32	22.3	0.52	0.90
Pooku	47.5- 75	0.04	5.50	5.10	5.35	26.2	1.64	2.83
Terra Roxa Legitima	90 -105	0.04	7.10	6.47	6.01	24.5	0.78	1.34
	105 -160	0.10	6.65	6.57	6.22	23.8	0.68	1.17
	160 -216	t	6.85	6.57	6.31	24.9	0.58	1.00
Sadao	80 -150	0.11	5.25	4.10	4.04	2.0	0.78	1.34
Siracha	28 -120	0.05	6.12	5.92	5.16	6.5	0.70	1.21
Thamai	80 -100	0.56	5.55	5.19	4.45	17.1	0.28	0.48
Yasothon	49 -500	0.33	5.35	5.62	4.20	1.2	0.20	0.34

Table Vb. Some Physical Properties of the Oxic Horizons

Soil	Depth cm	Water Dispersible Clay %	15-Bar Water Retention %	Particle Size Distribution		
				%Sand	%Silt	%Clay
Molokai	82.5-110	6.5	20.4	16.7	43.3	40.0
	110 -130	5.8	21.7	38.0	17.8	44.3
Pooku	47.5- 75	2.9	31.7	80.0	3.9	17.1
Terra Roxa Legitima	90 -105	7.5	22.5	16.6	11.7	71.7
	105 -160	5.2	23.4	28.4	39.2	32.4
	160 -216	4.9	23.5	24.7	4.5	71.4
Sadao	80 -150	4.7	6.2	74.5	6.2	19.3
Siracha	28 -120	21.8	15.5	35.4	36.8	27.9
Thamai	80 -100	4.4	31.4	6.3	20.1	73.6
Yasothon	49 -500	20.4	5.0	64.5	16.1	19.5

Table Vc. Differential Thermal Analysis of the Oxic Horizons

Soil	Depth cm	Low Temperature Endothermic Water	Kaolin	Gibbsite	Quartz
Molokai	82.5–110	w	m	w	–
	110 –130	w	m	w	–
Pooku	47.5– 75	m	–	s	–
Terra Roxa Legitima	90 –105	w	w	s	–
	105 –160	w	w	s	–
	160 –216	w	w	s	–
Sadao	80 –150	–	vw	vw	m
Siracha	28 –120	w	w	vw	w
Thamai	80 –100	w	m	vw	–
Yasothon	49 –500	vw	vw	vw	m

vw = very weak
w = weak
m = moderate
s = strong

Table Vd. X-ray Diffraction Analysis of the Oxic Horizons

Soil	Depth cm	Size Fraction μ	Q	Gb	G	Ma	He	A	K	Mi	Ch
Molokai	82.5-110	>50	-	-	-	-	-	-	vw	-	-
		2-50	-	-	-	w	w	-	w	-	-
		<2	vw	vw	-	-	-	-	m	-	-
	110 -130	>50	-	-	-	-	-	-	vw	-	-
		2-50	-	-	-	w	w	-	w	-	-
		<2	-	-	-	-	-	-	m	-	-
Pooku	75 -100	>50	-	s	vw	-	vw	-	-	-	-
		2-50	-	vs	vw	vw	vw	-	-	-	-
		<2	-	s	-	-	-	w	-	-	-
Terra Roxa Legitima	90 -105	>50	vs	w	-	-	vw	-	vw	-	-
		2-50	vs	vs	-	-	w	-	vw	-	-
		<2	-	m	-	-	-	-	m	-	-
	105 -160	>50	vs	w	-	-	vw	-	vw	-	-
		2-50	vs	vs	-	-	w	-	vw	-	-
		<2	-	m	-	-	-	-	m	-	-
	160 -216	>50	vs	w	-	-	vw	-	vw	-	-
		2-50	vs	vs	-	-	w	-	vw	-	-
		<2	-	m	-	-	-	-	m	-	-

Table Vd. X-ray Diffraction Analysis of the Oxic Horizons (Continued)

Soil	Depth cm	Size Fraction u	Q	Gb	G	Ma	He	A	K	Mi	Ch
Sadao	80 -150	>50	vs	-	-	-	-	-	w(b)	-	-
		2-50	vs	-	-	-	-	-	w(b)	-	-
		<2	w	-	-	-	-	-	vs	vw	-
Siracha	28 -120	>50	vs	-	-	-	-	-	w(b)	vw	-
		2-50	vs	-	-	-	-	-	w(b)	vs	-
		<2	vw	-	-	-	-	-	s	vw	-
Thamai	80 -100	>50	vs	-	-	-	-	-	-	-	-
		2-50	vs	-	-	-	-	-	w(b)	-	-
		<2									
Yasothon	49 -500	>50	s	-	-	-	-	-	w(b)	-	vw
		2-50	s	-	-	-	-	-	m	-	-
		<2	m	-	-	-	-	-	vs	vw	-

s = strong
m = moderate
w = weak
w(b) = weak (broad)
vw = very weak
vw(b) = very weak (broad)
- = none; not detected

Q = Quartz
Gb = Gibbsite
G = Goethite
Ma = Magnetite
He = Hematite
A = Anatase
K = Kaolin
Mi = Mica
Ch = Chlorite

Table Ve. Some Other Properties of the Oxic Horizons

Soil	Depth cm	Cation Retention (NH_4Cl) meq/100g clay	CEC (NH_4OAc pH 7) meq/100g clay	Bases + KCl Extractable Al meq/100g clay	pH ($pH_{KCl}-pH_{H_2O}$)
Molokai	82.5–110	13.2	15.2	5.96	-0.15
	110 -130	12.9	13.5	6.32	-0.40
Pooku	47.5– 75	7.6	17.1	0.26	+0.25
Terra Roxa Legitima	90 -105	5.4	9.7	0.63	-0.46
	105 -160	5.6	10.1	0.82	-0.35
	160 -216	4.2	7.5	0.46	-0.24
Sadao	80 -150	6.8	7.6	1.66	-0.35
Siracha	28 -120	18.5	24.6	11.44	-0.76
Thamai	80 -100	10.4	12.5	1.39	-0.74
Yasothon	49 -500	8.1	11.1	3.74	-1.42

Table Ve. Some Other Properties of the Oxic Horizons (Continued)

Soil	Depth cm	% Clay (2.5 X 15-bar water)	% 15-Bar Water/% Clay
Molokai	82.5-110	51.0	0.51
	110 -130	54.3	0.49
Pooku	47.5- 75	79.3	1.85
Terra Roxa Legitima	90 -105	56.3	0.31
	105 -160	58.5	0.72
	160 -216	58.8	0.33
Sadao	80 -150	15.5	0.32
Siracha	28 -120	38.8	0.56
Thamai	80 -100	78.0	0.43
Yasothon	49 -500	12.5	0.26

Chemical Properties

The results of the chemical analysis are shown in Tables Ia, Ie, IIa, IIe, IIIa, IIIe, IVa, IVe, Va, and Ve.

Cation Retention

The results are expressed as either meq/100 g of soil or meq/100 g of clay. The clay content of the latter was obtained from the higher value of either the pipette method of particle size distribution or 2.5 x 15-bar water. The cation retention ranged from 0.9 to 12 meq/100 g of soil or 4 to 23 meq/100 g of clay. The Molokai soil profile and the oxic horizons of the Siracha and Thamai soils showed cation retention values greater than 10 meq/100 g of clay, a value prescribed by the Soil Survey Staff (1967) for the oxic horizons. In general, the other soils showed values close to or less than 10 meq/100 g of clay.

This analysis was carried out because the results can be used to differentiate highly allophanic soils with pH dependent charge from the Oxisols. The latter show little or no difference between the values of cation retention and cation exchange capacity. A small difference indicates that the exchange capacity is not pH dependent.

Cation Exchange Capacity (CEC)

Cation exchange capacity is also expressed as meq/100 g of clay. The CEC results ranged from 6.2 to 27.6 meq/100 g of clay. In general, the highest CEC value in a profile was in the surface horizon. In the Pooku soil, however, the highest value was in the second horizon (Ap_2). Except for the Pooku and Siracha soils, the CEC of the oxic horizons was well below 16 meq/100 g of clay which is the value prescribed by the Soil Survey Staff (1967).

Cation exchange capacity is one of the important characteristics used to identify an oxic horizon. A low cation exchange capacity value determined at pH 7 distinguishes the oxic horizon from the cambic horizon which has a higher CEC and contains weatherable minerals which can release bases.

Low CEC indicates the low activity of the clay probably due to the old age of the soil, old in the sense that there are no weatherable minerals and the soil seems to be the end product of weathering.

Bases and Percent Base Saturation

Base saturation values ranged from 1 percent to approximately 50 percent. The amounts of sodium, potassium, calcium, and magnesium ions released or appearing at the exchange sites normally depend on the kind and amount of weatherable minerals.

Oxisols are old soils which contain little or no weatherable minerals. Therefore, the amount of bases is related to the intensity of leaching which remove the bases from the soils. A high base saturation may indicate low rainfall or a young Oxisol.

However, the limits on the bases as well as base saturation in Oxisols are not discussed by the Soil Survey Staff (1967).

The Sum of Extractable Bases and KCl-Extractable Aluminum

The results show that the sum of extractable bases and KCl-extractable aluminum was less than 10 meq/100 g of clay for all soils except the Siracha horizon. According to the Soil Survey Staff (1967), the sum of these cations is less than 10 meq/100 g of clay. The sum of the extractable bases and KCl-extractable aluminum was generally low for each soil. The results ranged from 0.2 to 13.4 meq/100 g clay and was commonly high at the surface.

The sum of extractable bases and KCl-extractable aluminum for an acidic soil is similar to permanent exchange capacity (Soil Survey Staff, 1967). This fact suggests that the soils with oxic horizons are relatively inert.

Soil pH

In most cases, the pH values in water were higher than those in KCl solution. Thus, almost all of the horizons had a net negative charge. The exceptions were the four horizons B_{21} to C_2 of the Pooku soil and the two horizons C_5 and C_8 of the Terra Roxa Legitima which had net positive charge.

Generally, the total charge of a soil develops from negative and positive charges of silicate clay particles and colloidal iron and aluminum oxides. The organic matter may carry either a negative or positive charge depending on its isoelectric point. The net charge is influenced by the soil pH. Delta pH is affected by proportions of positive and negative charges.

Free Iron Oxide

Hematite and goethite are primarily extracted by the dithionite method. Some of the resistant iron minerals may also be slightly affected. Coffin (1963) found that less than 10% of the crystalline iron and other oxides was extracted. Other oxides such as siderite, ilmenite, and lepidocrocite were also found in the extract. The amount and kind of oxides depended upon the size and the kind of parent rock. According to this study soils of basic parent materials showed large amounts (>15%) of free iron oxides. The acidic and intermediate parent materials showed low and intermediate amounts of free iron oxides; for example the Sadao and the Siracha soils, respectively.

In this study, the free iron oxides did not show any significant relation to any property. The oxides, however, seemed to play an important role in soil structure and seemed to be responsible for the incomplete dispersion of the clay. Many investigators have directed their studies to iron oxides. Sumner (1963) studied the effect of iron oxides on positive and negative charges of clays and soils and concluded that iron oxides increased the buffering capacity of soil. Charges on iron oxides were pH-dependent, being positive at low pH and negative at high pH. Thus, the negative charge on clay decreased at low pH and increased at high pH. Deb (1950) found that after removal of free iron oxides, the exchange capacity increased, possibly due to either the removal of fixed exchange iron or aluminum or the removal of $Al(OH)_2^+$ from the outer edges of the crystal. Greenland (1968) studied iron oxides in some red soils by electron microscopy and concluded that the free iron oxides were small discrete particles ranging in size from 50 to 100 A in diameter. These oxides were frequently found along the edge rather than the surface of the clay; for example the surface of kaolinite plates.

The amount of free iron oxides did not appear to be related to the age of the soils but it did appear to be dependent on the parent material and other unknown factors and to be responsible for soil color.

Organic Matter

In general, the Oxisols contain small amounts of organic matter. In this study, the surface horizons showed the highest amount of organic matter in the profile. The exception was the Ap_2 horizon of the Pooku soil. All the soils, except the Pooku and the Terra Roxa Legitima, have more than 1% organic carbon in the second horizon. This horizon seemed to show a high retention of organic matter by iron oxides. The retention of organic matter by iron oxide is mentioned by Coffin (1963).

Physical Properties

The physical properties of all soils are shown in Tables Ib, IIb, IIIb, and Vb.

Particle Size Distribution

The main objective of the particle size distribution analysis was to determine the clay content so that the cation exchange capacity data could be expressed as meq/100 g of clay. The textural class name is unimportant because it can range from loamy sand or sandy loam to clay, as long as the clay content exceeds 15%.

The clay content obtained in this investigation met the requirement of the oxic horizon.

The sand fractions, one horizon of each soil after separation from silt and clay, were studied by means of a petrographic microscope. The objectives were to determine whether or not the soils were completely dispersed and to identify the mineral grains. The sand fraction of the third horizon of the Molokai soil was primarily aggregates of clay containing unweathered magnetite. There were also small to moderate amounts of fine grains of altered olivine. The sand fraction of the fourth horizon of the Pooku soil was made up of approximately equal amounts of gibbsite and magnetite. Although much of these minerals were fine-grained, some of the magnetite was large-grained. The grains of gibbsite were cemented by iron stained clay. As in the case of the Molokai soil, the sand fraction of the fourth horizon of the Terra Roxa Legitima was primarily aggregates of iron stained clay containing many fine grains of magnetite. The sand fractions of the Sadao and Yasothon soils contained fine to coarse grains of quartz with traces of clay, while that of the Siracha soil contained not only many small grains of quartz but also few fine to moderate sized grains of magnetite. The Thamai sand fraction also contained many fine grains of quartz which were coated with iron oxide stained clay-like material. Both the Sadao and the Yasothon soils are derived from a metamorphic rock of intermediate composition. The Thamai soil is believed to have been derived from basic igneous parent rock.

The soils derived from acidic parent material appeared to be completely dispersed while those derived from basic parent material appeared to be incompletely dispersed as evidenced by the presence of aggregates of clay stained with iron oxide.

Citrate-dithionite extraction followed by particle size distribution analysis, as suggested by the Soil Survey Staff (1967), is very useful for studying soil minerals but it appears to be an impractical method for obtaining the clay content. There are many involved steps in the analysis accompanied by not only some loss of free alumina and silica during deferration but also by physical loss of the various fractions during mechanical analysis. If the above method were used as a standard procedure, there would need to be some change in the definition of the oxic horizon, especially in the limit of cation exchange capacity. As mentioned in the discussion of free iron oxides, deferration was observed by some workers to increase the exchange capacity of soils.

An experiment was carried out to determine an efficient way of dispersing the oxic horizon of the Molokai soil. A natural sample and a Na-saturated sample, washed free of excess salt, were dispersed with varying amounts of sodium hexametaphosphate. The procedure used was that of Kilmer and Alexander (1949) except that the following amounts of the dispersing agent were used in the different treatments:

10 ml of 25 g/liter of water

10 ml of 50 g/liter of water

10 ml of 100 g/liter of water

The results showed that 10 ml of 50 g of the dispersing agent per liter of water, the amount prescribed by Kilmer and Alexander, was most efficient. Furthermore, the Na-saturated sample showed only 2-3% more clay than the natural sample, thereby indicating that Na-saturation does not significantly increase the dispersion of the Molokai soil when sodium hexametaphosphate is used. The sand fraction still contained aggregates of clay stained with iron oxide.

The dispersion of tropical soils, such as the Molokai soil which are derived from basic igneous parent rock, presents a problem. It is essential, therefore, that an effective method of dispersion be worked out for future investigation to obtain data which can be used for classifying soils.

<u>Water-Dispersible Clay</u>

Following the discussion of the Soil Survey Staff (1967), the amount of water-dispersible clay was used to locate the upper boundary of the oxic horizon. The four profiles, Molokai, Pooku, Terra Roxa Legitima, and Sadao soils all showed a marked drop in the amount of water-dispersible clay in the oxic horizon.

The Siracha and Yasothon soils showed the values of water-dispersible clay to be much higher than the limit of the oxic horizon while those of other soils showed small amounts of water-dispersible clay. The oxic horizon of the Pooku soil was the only one which contained less than 3% water-dispersible clay, but the others were still low, ranging from 4.4 to 7.5% (Table Vb).

The low content of water-dispersible clay in the Molokai and Pooku soils were located in the horizon designated as B horizons. The low content of water-dispersible clay in the Pooku soil was located in the horizon which was slightly less than 30 cm thick. This horizon of the Terra Roxa Legitima and Sadao soils was lower than the upper B horizon.

The results showed that there was no relationship between water-dispersible clay and the amount of free iron oxide or to any of the other properties studied in this investigation. Perhaps the reason for the low water-dispersible clay may be related to the low activity and nature of the clay or to the isoelectric point in the oxic horizon.

15-Bar Water Retention

Results in Tables Ib, IIb, IIIb, IVb, and Vb show that the water held at 15-bar tension ranged from 4 to 32%. The Molokai soil averaged 20%, while the Pooku soil ranged from about 18 to 32%. The Terra Roxa Legitima ranged from 20 to 24%. The soils from Thailand ranged from 4 to 32%, Thamai with the highest percentage.

Moisture retention depends on the structural make up of clay and the amount of organic matter. In general, the amount of organic matter is low in the Oxisols. Therefore, the use of the value 2.5 x 15-bar water to estimate the clay content seems reasonable. This clay content was used to establish the limit of cation retention, cation exchange capacity, and permanent exchange capacity in the oxic horizon whenever the clay content by the pipette method was low.

The Ratio of Percent 15-Bar Water Retention to Percent Clay

The percent clay used in calculating the ratio was taken from the particle size distribution analysis obtained by the pipette method. According to the Soil Survey Staff (1967), the ratio does not exceed 0.5 if the clay disperses. Furthermore, samples with ratios exceeding 0.5 could be dispersed more after the citrate-dithionite treatment.

The ratios obtained in this study (Tables Ie, IIe, IIIe, IVe, and Ve) showed that, in general, there was effective dispersion in most of the soils. The ratio of the Molokai soil ranged from 0.4 to 0.6, while that of the Pooku soil ranged from 0.9 to 3.4. The ratio of the Terra Roxa Legitima ranged from 0.3 to 0.6. The ratio of the Sadao soil ranged from 0.32 to 0.44, while those of the Siracha, Thamai, and Yasothon horizons were 0.56, 0.43, and 0.26, respectively. Within a profile some horizons showed less dispersion than others; for example, the Ap_1 horizon of the Molokai soil and the IIB_3, C_5, C_8, and C_9 horizons of the Terra Roxa Legitima. As shown in Table IIe, the ratio of the Pooku soil also indicates that this soil was very poorly dispersed.

The petrographic study of immersion mounts of the selected sand fractions of Hawaiian soils suggest that the 15-bar water/clay ratio is not a reliable variable to measure the degree of dispersion. Although the ratio of the oxic horizon of the Molokai soil is 0.5, much of the sand fraction was composed of clay aggregates. Furthermore, although the ratios of the Pooku horizons are high, the sand fractions were primarily fragments of gibbsite and iron and/or titanium oxide, cemented by iron stained clay. On the other hand, the ratio appears to be a reliable measure of dispersion in the Thai soils.

Mineralogical Properties

Tables Ic, IIc, IIIc, and IVc show the results of the differential thermal analysis of the four soil profiles and the three oxic horizons. The differential thermal curves are present in Fig. Ia through Fig. Va.

The low temperature endotherm at approximately 100°C is attributed to the presence of adsorbed water or to allophane (Fieldes, 1955). Differentiation of the types of allophane has been made by Fieldes based on the presence or absence of the exothermic peak at approximately 900°C. The endothermic peak at approximately 350°C is characteristic of gibbsite, and the endothermic peak at approximately 500°C followed by a high temperature exotherm near 900°C is characteristic of kaolin.

Kaolin and gibbsite are the dominant minerals in the samples from Hawaii and Brazil. On the other hand, quartz (endotherm at 573°C) is detected in most of the samples from Thailand. Since the endothermic peak of hydrous oxides of iron occur at approximately the same temperature range as gibbsite, (Jackson, 1956), for purposes of discussion the former will be reported as gibbsite.

The Molokai soil contained moderate amounts of kaolin which increased slightly with depth. The upper two horizons, furthermore, contained moderate amounts of gibbsite while the lower two horizons contained only a very small amount of the same mineral.

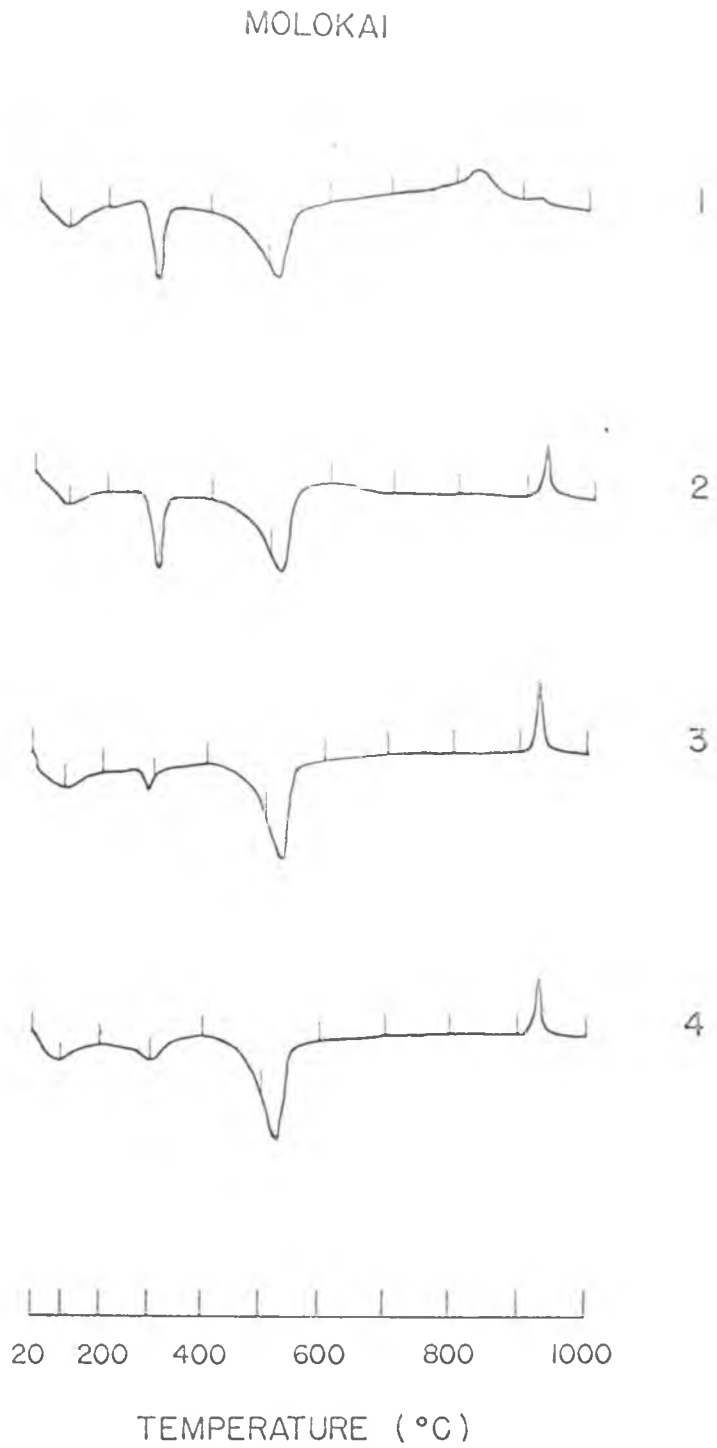

Fig. Ia. Differential Thermal Curves of Whole Soil in the Profile of Molokai Soil.

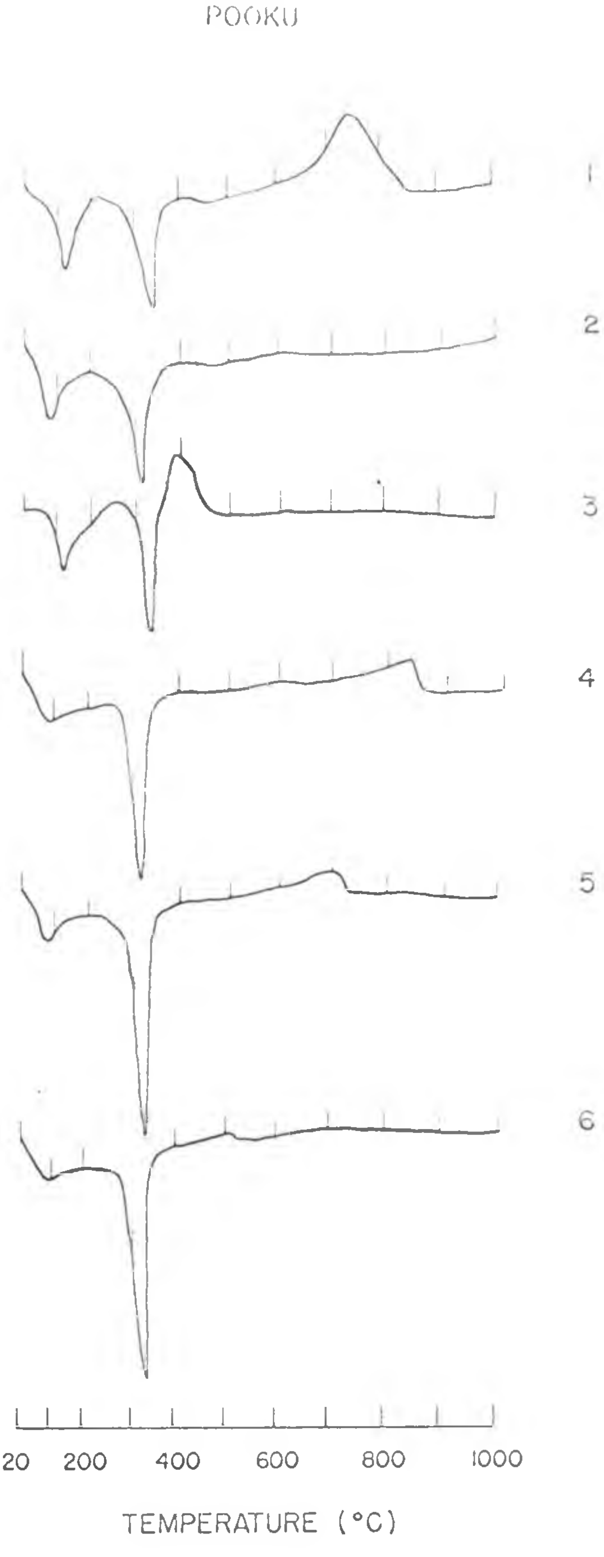

Fig. IIa. Differential Thermal Curves of Whole Soil in the Profile of Pooku Soil.

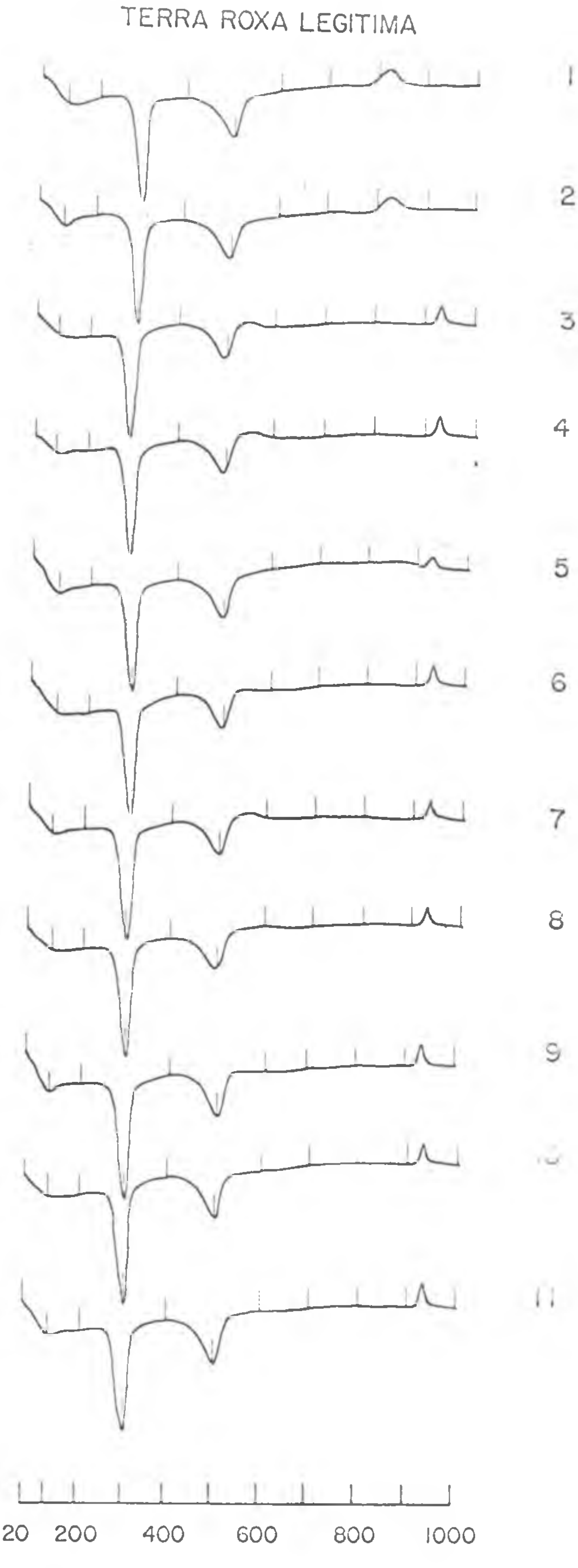

Fig. IIIa. Differential Thermal Curves of Whole Soil in the Profile of Terra Roxa Legitima Soil.

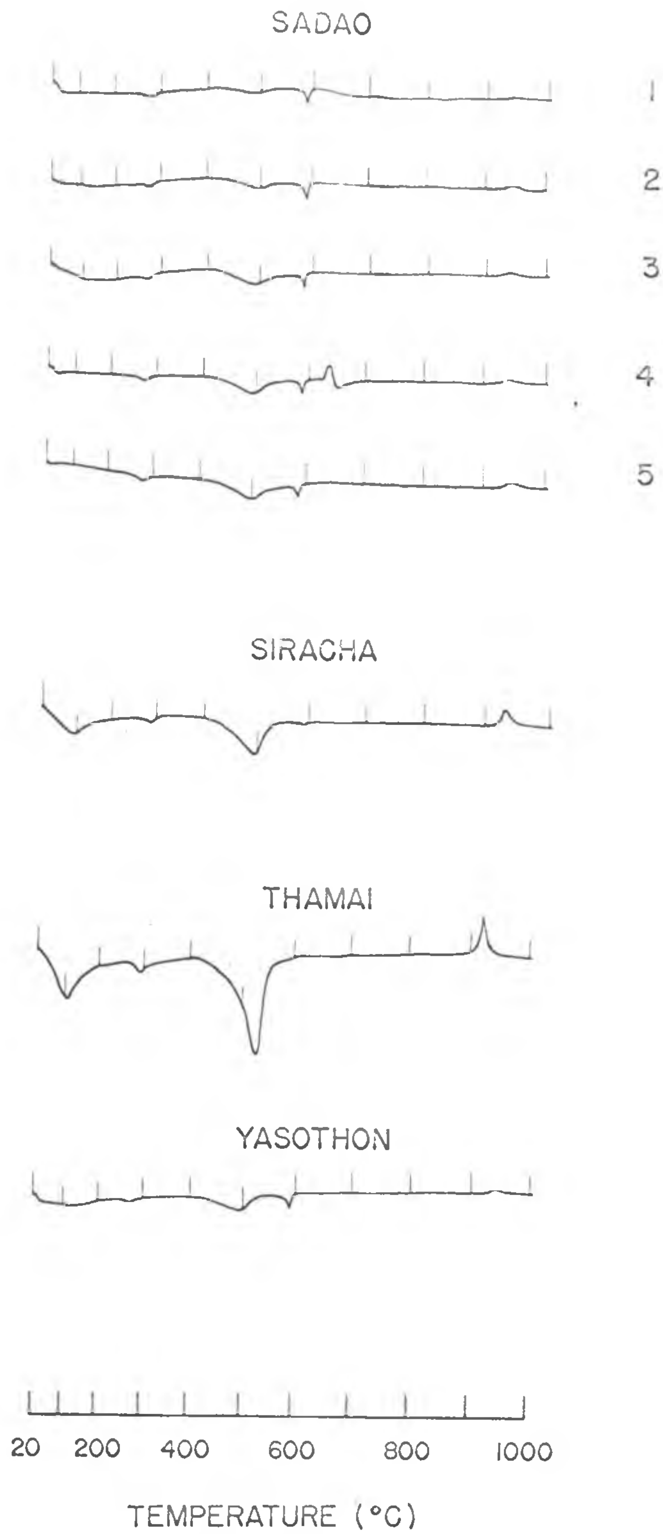

Fig. IVa. Differential Thermal Curves of Whole Soil in the Profile of Sadao Soil and the Oxic Horizons of the Soils from Thailand.

The Pooku soil contained large amounts of gibbsite which increased with depth. The exothermic peaks which occur between 700° and 850°C in the first, fourth, and fifth horizons are not definitely identified but may be contributed to the presence of amorphous material. The exothermic peak at 400°C in the third horizon is characteristic of an iron rich soil.

The Terra Roxa Legitima was very uniform in mineralogy throughout the profile. This soil was characterized by the presence of large amounts of gibbsite and a small amount of kaolin. The Sadao soil was characterized by the presence of quartz and a very small amount of kaolin and gibbsite. Except for the small exothermic peak at approximately 640°C in horizon four, the mineralogy of this soil is also very uniform throughout the profile.

The Siracha and Thamai horizons were similar in mineralogy, containing kaolin and very small amounts of gibbsite. The only exception was the presence of quartz in the former. The Yasothon horizon was similar to the Sadao soil in that it contained quartz and very small amounts of kaolin and gibbsite.

The amount of minerals determined by x-ray diffraction analysis is based on the intensities of the diffraction peaks. The peak intensities were classified as very strong, strong, moderate, weak, and very weak. These values provided a means of comparing the mineralogical differences within and between the profiles of the different soils.

The mineralogical composition of the Molokai soil is constant throughout the profile. Although x-ray amorphous material may be common, kaolin is dominant in the clay fraction (Fig. lb). The very weak to weak peaks of kaolin observed in the x-ray patterns of the selected sand fractions indicate incomplete dispersion. Quartz and traces of mica were present in the sand and clay fractions, respectively, of the first two horizons. Small amounts of these minerals were also present in the third horizon. Furthermore, Table Id shows small amounts of magnetite and hematite in the sand and/or silt fractions throughout the profile.

Since primary quartz and mica are not present in Hawaiian rocks the quartz and mica found in the upper horizons of the Molokai soil may be considered to be secondary minerals. The presence of the small to moderate 02 hk reflection shown at approximately 20° 2θ (Fig. lb) indicates that the kaolin is either a halloysite or a disordered kaolinite.

In the Pooku soil, only the oxides of aluminum, iron, and titanium were observed (Table IId). Traces of kaolin (7.14 A) and large amounts of quartz were detected in the surface horizon. The amount of quartz somewhat decreased in the second horizon. Gibbsite, goethite, hematite, magnetite, were also found in the horizon. Anatase, which is a heavy mineral, was found only in the clay fraction, indicating that this mineral may be very fine grained.

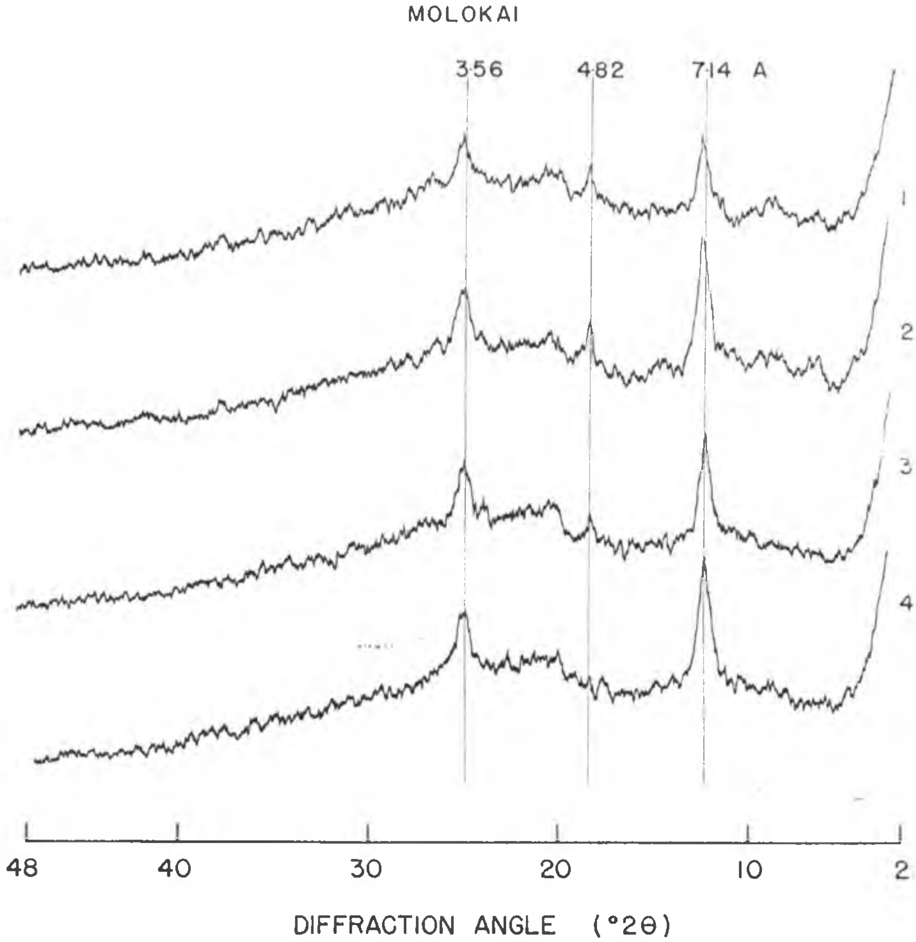

Fig. Ib. X-ray Diffraction Patterns of K-Saturated Clay in the Profile of Molokai Soil.

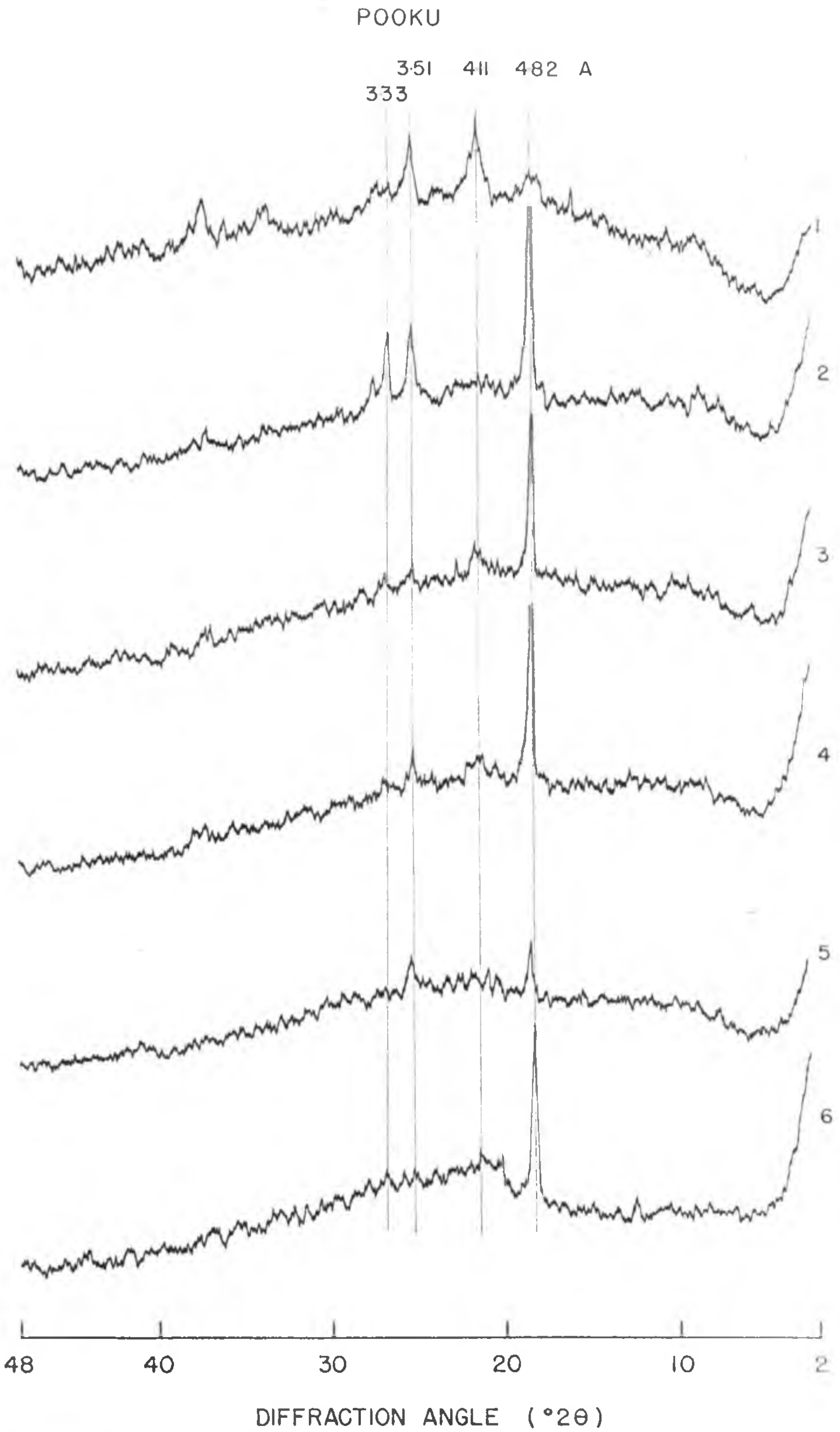

Fig. IIb. X-ray Diffraction Patterns of K-Saturated Clay in the Profile of Pooku Soil.

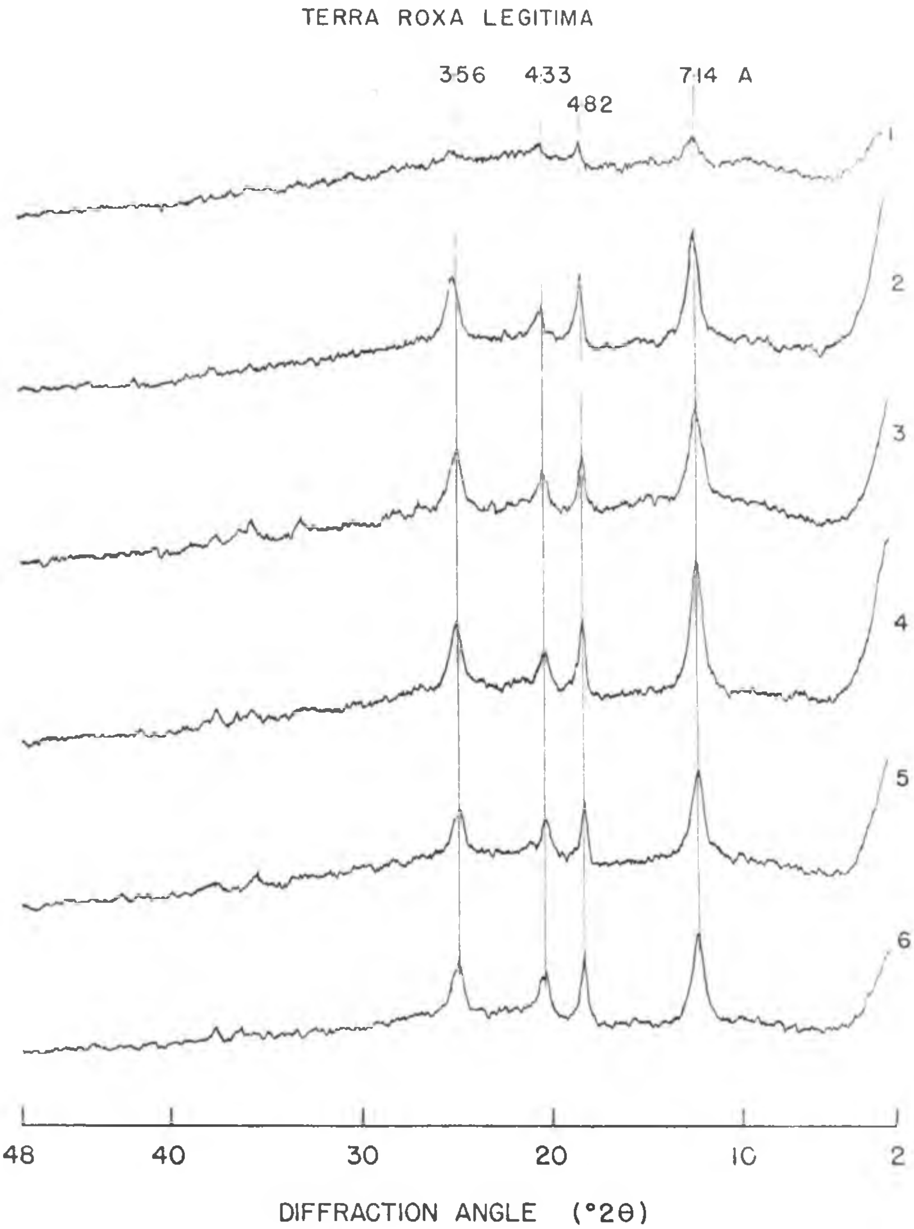

Fig. IIIb. X-ray Diffraction Patterns of K-Saturated Clay in the Profile of Terra Roxa Legitima Soil.

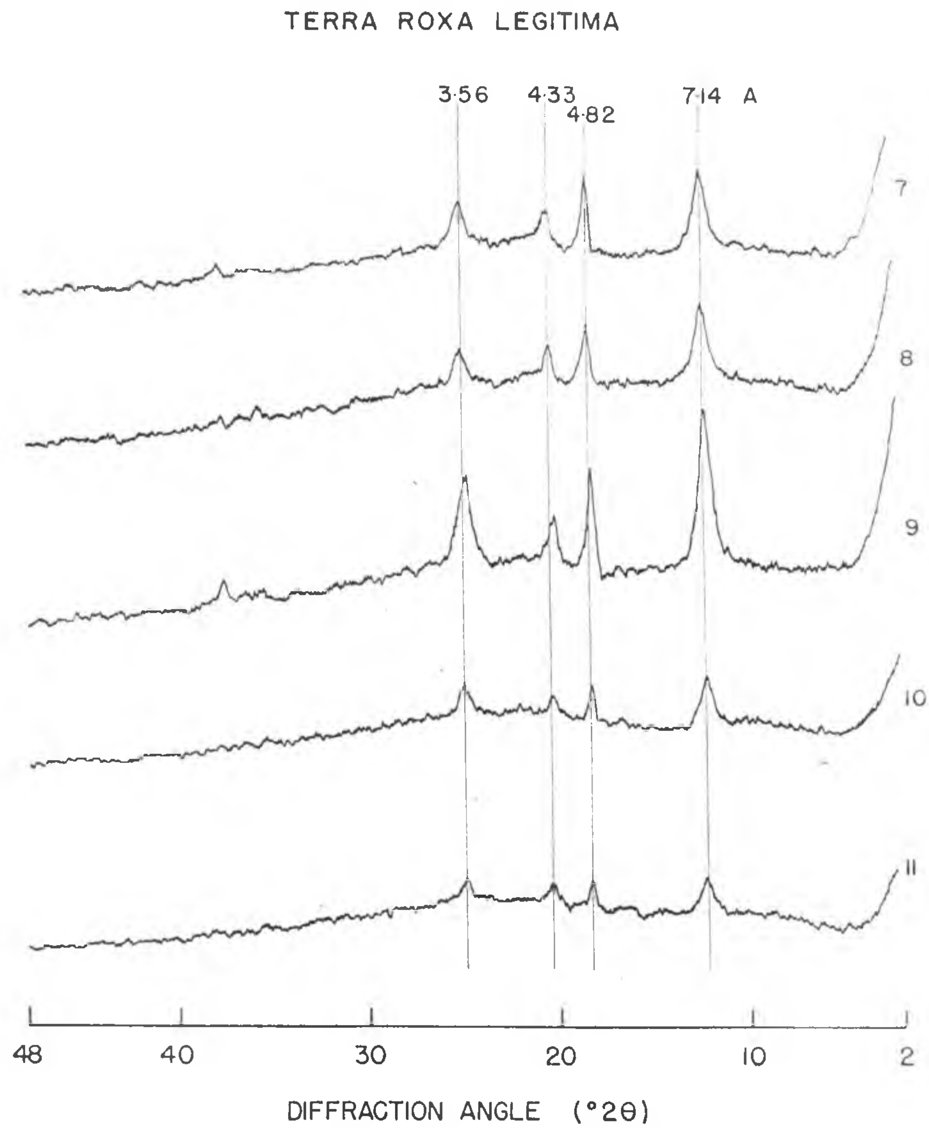

Fig. IIIb. X-ray Diffraction Patterns of K-Saturated Clay in the Profile of Terra Roxa Legitima Soil (Continued).

The x-ray diffraction patterns of the sand and silt fractions of the Terra Roxa Legitima showed strong peaks of quartz. The gibbsite peak was very weak in the sand fraction but very strong in the silt fraction. Hematite was very weak in both fractions. Kaolin and gibbsite peaks were weak in the clay fraction of the surface and the last two horizons. Moderate to strong peaks were observed in the remaining horizons.

The Sadao soil contained predominantly kaolin, a small amount of quartz, and traces of mica in the clay fraction (Fig. IVb). The presence of mica was confirmed by the heat treatments of the K-saturated sample. No iron oxide was detected, probably because it was removed during the citrate-dithionite treatment. The presence of strong 7 and 3.5 A lines and the absence of the 02 hk reflection band indicate the occurrence of the mineral kaolinite. It is obvious that DTA results of the whole soil show only small amounts of kaolin. On the other hand, the clay fraction shows large amounts of kaolin. These results may indicate good dispersion or separation of quartz in the coarser fraction and the clay in the finer or clay-sized fraction.

The oxic horizon of the Siracha soil contained quartz, kaolinite, and mica. There was more than a trace of mica because both the silt and clay fractions showed the peaks of mica. The diffraction lines suggest that the mica may possibly be phlogopite.

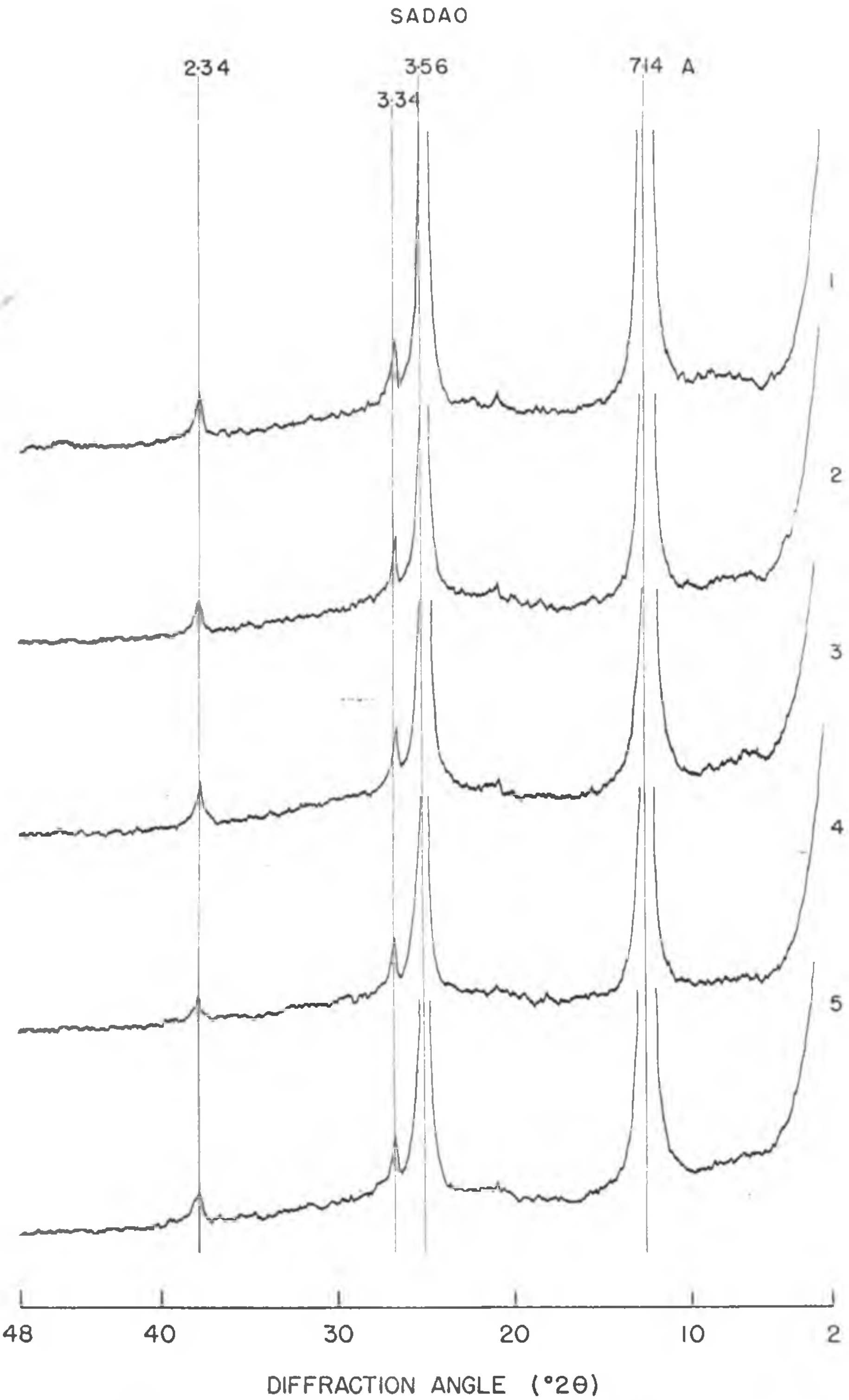

Fig. IVb. X-ray Diffraction Patterns of K-Saturated Clay in the Profile of Sadao Soil.

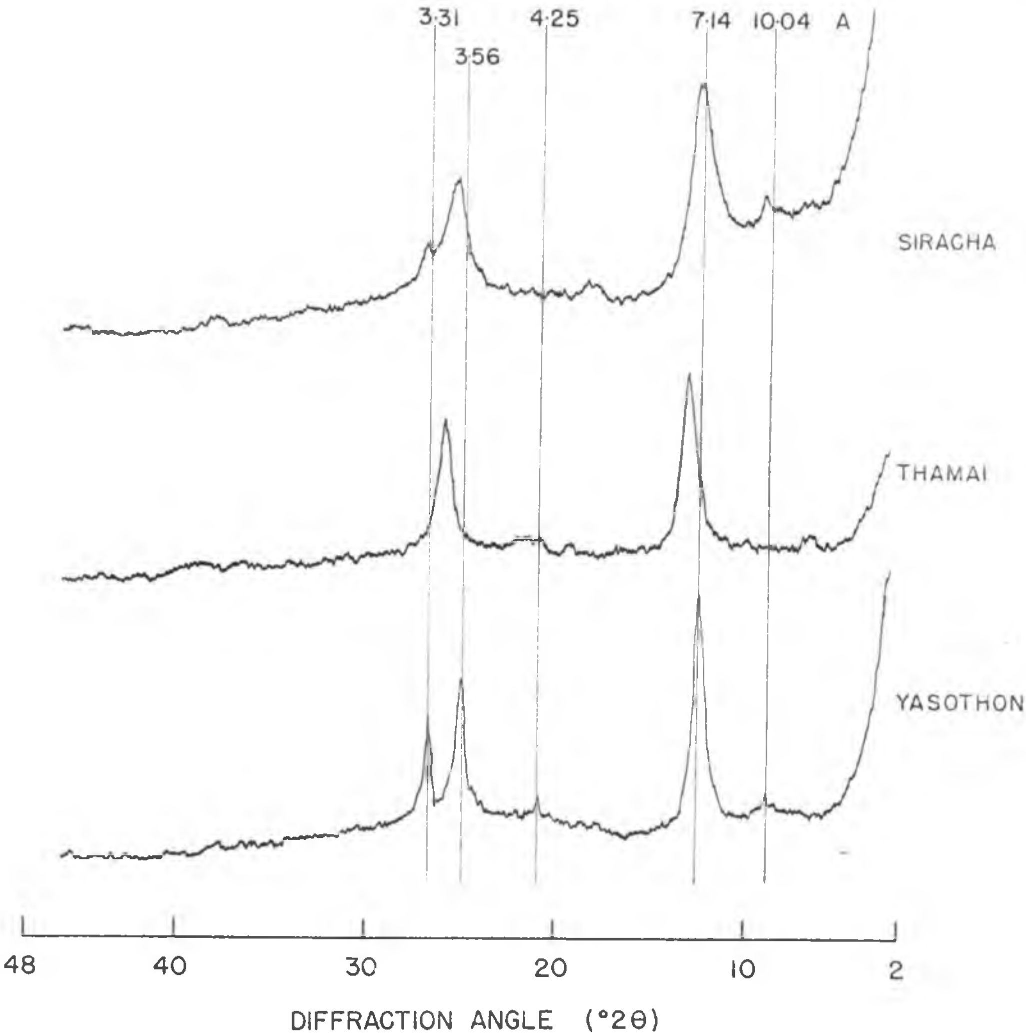

Fig. Vb. X-ray Diffraction Patterns of K-Saturated Clay in the Oxic Horizons of the Soils from Thailand.

The oxic horizon of the Thamai soil contained primarily quartz in the sand fraction and primarily kaolinite in the clay fraction. Although the soil was composed mainly of quartz and kaolinite, a trace amount of chlorite was also detected.

The oxic horizon of the Yasothon soil consisted mainly of quartz and kaolinite with traces of mica. As in the case of the other samples from Thailand, quartz was predominant in the sand fraction, while kaolinite was predominant in the clay fraction.

Profile Characteristics

Profiles of the Molokai, Pooku, Terra Roxa Legitima, and Sadao soils were studied. Table VI shows the genetic factors and some of the physical, chemical, and mineralogical properties of these soils.

Molokai Soil

The Molokai soil was previously classified as a Low Humic Latosol. This soil is located in a lower rainfall area than the other Low Humic Latosols of Hawaii.

The surface horizon exhibits very weak coarse granular structure, while the second horizon has coarse prismatic structure. The oxic horizon showed weak to strong angular to subangular blocky structure, and the lower oxic horizon showed very thin patchy clay film on peds. Iron-manganese concretions were also found in this soil.

Table VI. Some Characteristics of the Four Soil Profiles

Characteristics	Molokai	Pooku	Terra Roxa Legitima	Sadao
Structure				
Surface horizon	VW coarse granular	S subangular blocky	fine to very fine subangular blocky	W medium to fine subangular blocky
Oxic horizon	W to M blocky	W fine subangular blocky	poorly developed subangular blocky	W fine subangular blocky
Texture	clay	clay	clay	sandy loam
Color (surface)	2.5YR 3/4	10YR 4/4	10R 3/3	5YR 4/4
Consistence	hard, friable sticky, plastic	friable sticky, plastic	friable sticky, plastic	friable non-sticky non-plastic
Parent material	basic igneous rock	basic igneous rock	basalt	old alluvium
Rainfall mm	325-625	2,032-2,331	1,300	2,413
Temperature C	22.8	21.7	21.5	27.2
% Slope	0-2	1-2	5-10	2-8

Table VI. Some Characteristics of the Four Soil Profiles (Continued)

Characteristics	Molokai	Pooku	Terra Roxa Legitima	Sadao
% Base saturation	41.3	3.4	7	14
% free iron oxide	20.5	25.5	24.3	1.3
% 15-bar water retention	20.7	27.9	22.8	5.1
Mineralogical composition	Q, Gb, Ma, K, Mi, Ol.	Gb, G, He, A.	Q, Gb, He, K.	Q, K, Mi.

S = Strong　Q = Quartz　Ma = Magnetite　K = Kaolin
W = Weak　Gb = Gibbsite　He = Hematite　Mi = Mica
M = Moderate　G = Goethite　A = Anatase　Ol = Olivine

Chemical composition taken from the average.

The cation exchange capacity, bases, and organic matter were higher at the surface than at the subsurface horizons. The pH values indicated this soil was slightly acidic to neutral. The pH in water is higher than the pH values in 1 N KCl solution, suggesting that the soil has a net negative charge throughout the profile. The amount of free iron oxides increased with depth.

The mineralogical composition of the Molokai soil was mainly kaolin and the oxides of aluminum such as gibbsite and the oxides of iron such as magnetite and hematite. These oxides seemed to be concentrated in the upper two horizons. Altered olivine was observed by means of the petrographic microscope. The presence of such a weatherable mineral indicates a young soil.

Pooku Soil

The Pooku soil was previously classified as a Humic Ferruginous Latosol. This soil occurs in a high rainfall area but with a lower rainfall than the Molokai soil.

The structure is blocky in the upper four horizons and platy and massive in the fifth and sixth horizons. Many iron concretions were found in the Ap_1 and Ap_2 horizons. Hematite and gibbsite as well as thick cutans are found in the C_1 horizon which is below the oxic horizon.

The CEC, organic matter, and free iron oxide values were highest in the second horizon. The ΔpH values of the Ap_1 and Ap_2 were negative but the values of the horizons below were positive. The clay was not as completely dispersed as the Molokai.

The mineralogy of this soil was different from all of the other soils because it contained almost no silicate clay throughout the profile. Only traces of kaolin were detected in the surface horizon. The Pooku soil consisted primarily of gibbsite and crystalline and amorphous iron oxides and small amounts of anatase. There was some quartz in the surface horizon but this mineral was found in small amounts in the second horizon. The mineralogy further indicated the presence of an old soil or a highly weathered soil which has almost reached the end stage of weathering (Mohr, 1944).

Terra Roxa Legitima

The Terra Roxa Legitima soil is similar to the Low Humic Latosols of Hawaii (Bramao and Lemos, 1960). This soil developed under a higher rainfall than the Molokai soil. The temperatures of both areas, however, are approximately alike. According to the field description, the parent rock is a basalt, but Bramao and Lemos classify it as a diabase.

The cation exchange capacity and the base saturation of the Terra Roxa Legitima were lower than those of the Molokai soil. The organic matter was high in the upper two horizons, and the free iron oxides were distributed evenly throughout the profile. As in the case of the Hawaiian soils, there was evidence of incomplete dispersion. Except for the C_5 and C_8 horizons, all of the horizons showed a net negative charge.

In addition to gibbsite and kaolinite, quartz and hematite were present throughout the profile.

Sadao Soil

The Sadao soil, previously classified as a Red Latosol, is the only soil that is derived from acidic parent material. The rainfall and mean annual temperature are higher than those of the other three soils.

Weak structure prevailed throughout the profile. Pieces of charcoal were found in the subsurface horizons. In addition, a termite nest and thin patchy clay films were observed in the fifth horizon.

When the chemical properties of this soil are compared with those of the other soils, the CEC, exchangeable bases, and base saturation values of the Sadao soil are very low. Furthermore, this soil was strongly acid. The horizons had a net negative charge probably derived mainly from kaolinite.

The Sadao soil contained predominantly quartz with some kaolinite and traces of mica throughout the profile.

The results of this investigation suggest that the Molokai soil may be the youngest of the soils studied. The soils may be arranged chronologically as follows: Molokai < Terra Roxa Legitima < Pooku. It is difficult to place the Sadao in this series because of the differences in the parent material and in the effect of climate.

Comparison of Oxic Horizons

Tables Va through Ve and VIII show the properties of the oxic horizons.

In general, the properties of the oxic horizons meet the limitations set forth by the Soil Survey Staff (1967). The only exceptions were the cation retention (CEC by NH_4Cl) and water-dispersible clay values.

The differences in the cation retention value, however, appeared to be a minor one. The value was more than 10 meq/100 g of clay in the Molokai and Siracha horizons. Since the sum of the bases and KCl-extractable Al was well below 10 meq/100 g of clay in the Molokai horizon, this horizon may still be considered an oxic horizon. On the other hand, both measurements exceeded the limits in the Siracha horizon, thereby suggesting that the Siracha horizon may not be an oxic horizon.

Table VII further shows that the water-dispersible clay ranged from 2.9 to 21.8%. If the data of the Siracha and Yasothon horizons are excluded, the clay content of the other horizons ranged from 2.9 to 7.5% (mean = 5.2%). The profile distribution of the water-dispersible clay in the Molokai soil (Table Ib), Pooku soil (Table IIb), Terra Roxa Legitima (Table IIIb),

Table VII. Some of the Characteristics of the Oxic Horizons

Soil	Thickness cm	CEC meq/100g clay NH_4Cl	CEC meq/100g clay NH_4OAc	Bases + KCl Extractable Al meq/100g clay	Clay[1] %	Water Dispersible Clay %
Definition[2]	≥30	≤10	≤16	≤10	>15	<3
Molokai[3]	48+	13.0	14.4	6.14	53	6.2
Pooku	28	7.6	17.1	0.26	79	2.9
Terra Roxa[4]	126	5.1	9.1	0.64	67	8.9
Sadao	70+	6.8	7.6	1.66	19	4.7
Siracha	92+	18.5	24.6	11.44	39	21.8
Thamai	20+	10.4	12.5	1.39	78	4.4
Yasothon	451	8.1	11.1	3.74	15	20.4

[1]Higher value of the pipette method or 2.5 x 15-bar water.

[2]An oxic horizon as defined by Soil Survey Staff (1967).

[3]Two horizons represent the oxic horizon.

[4]Three horizons represent the oxic horizon.

and Sadao soil (Table IVb) clearly indicates the location of the oxic horizon. Although only the Pooku horizon showed less than 3% clay, the limit proposed by the Soil Survey Staff, the data suggest that the water-dispersible clay in the oxic horizon may be as high as 8 or even 10%.

The water-dispersible clay values of the Siracha and Yasothon horizons are high. The value of the former together with its cation retention value strongly suggest that it is not an oxic horizon. Based on the water-dispersible clay content, the Yasothon horizon also does not appear to be an oxic horizon. However, the distribution pattern in the profile does not support this belief.

Based on the results of this investigation, it is suggested, therefore, that the definition of the oxic horizon be modified so that this horizon may be identified in a profile by a low content of water-dispersible clay. Furthermore, the water-dispersible clay in the oxic horizon may be 10% instead of 3% as originally proposed by the Soil Survey Staff. It is further suggested that until an effective method of dispersion can be established to determine the clay content, the other requirements be used to identify the oxic horizon.

Some of the dissimilarities which were observed in the oxic horizons may be due to the genetic factors and the intensity of weathering. The differences in color were not considered very important, but it is interesting to note that the colors of the oxic horizons ranged from red to yellow. The red color of the Molokai, Terra Roxa Legitima and the color of the Pooku soils appeared to be related to the distribution and influence of the iron oxides within the horizons. Fripiat and Gastuche (1952) noted that the morphology of the iron oxides which were precipitated on the kaolinite surfaces depended upon the pH of the environment and the cation present. When kaolinite was H-saturated, the surface was porous and disordered and adsorbed large amounts of iron oxide. However, when kaolinite was saturated with other cations, the surface adsorbed small amounts of the oxide. Low base saturation indicated high exchange acidity and large amounts of iron oxides. For example, the Terra Roxa Legitima seemed to fit well in the first situation having low base saturation and a large amount of iron oxides. On another hand, the Molokai soil has high base saturation and lower amounts of iron oxides.

The oxic horizons differed slightly in the chemical properties but meet the requirements of the oxic horizon. Only the oxic horizon of the Pooku exhibited a net positive charge. The pH values of the oxic horizons ranged from strongly acidic to neutral. The two soils from Hawaii and the Terra Roxa Legitima had the highest amounts of free iron oxides.

As mentioned previously, there was a significant relationship between 15-bar water and the clay content. The 15-bar water/clay content ratio varied from less than 0.5 to 1.85. The ratio did not appear to be a good indicator of effective dispersion of the soil.

The mineralogical composition clearly showed the differences among the soils. The composition was related to the kind of parent materials from which the soil was derived. Three kinds of parent materials were encountered in this study. After deferration, the soils derived from basaltic rocks showed the presence of crystalline oxides of iron, aluminum, and titanium. The exception was the Thamai soil.

Table Vd shows the mineral composition of deferrated oxic horizons. The absence of any oxides in the Thamai soil probably indicates that oxides were very fine grained and easily extracted from the soil.

The weathering sequence of minerals has been presented by Jackson and Sherman (1955). Although the soils used in this investigation may differ in age, the mineral distribution certainly indicates that these soils are in the advanced stage of chemical weathering. For soils derived from basic parent material the Molokai soil appears to be the youngest while the Pooku appears to be the oldest and are listed by age as follows: Molokai < Thamai < Terra Roxa Legitima < Pooku.

SUMMARY AND CONCLUSIONS

The chemical, physical, mineralogical properties of the oxic horizons in some soils from Hawaii, Brazil, and Thailand were investigated. The other objectives of the comparative studies of the oxic horizons were to test the definition of this horizon and to modify it where necessary. Based on the results of this investigation, the following conclusions are made:

1. Variations in most of the properties of the soils used in this investigation are due to the influence of parent material, its age, and the effect of climate on the intensity of weathering.
2. The CEC seems to be correlated to the amount of water retained at 15-bar tension.
3. The amount of free iron oxides in the Oxisols may not be related to the degree of weathering or the age of parent material but may be related to the kind of parent material.
4. Based on the results of this investigation, it is suggested that the definition of the oxic horizon be modified so that this horizon may be identified in a profile by a low content of water-dispersible clay. The water-dispersible clay in the oxic horizon may be 10% instead of 3% as originally proposed by the Soil Survey Staff.

5. Determination of the clay content by using sodium hexametaphosphate as a dispersing agent is suitable for Oxisols derived from acidic parent material but not quite satisfactory for the Oxisols derived from basic parent material.
6. The value 2.5 x percent 15-bar water gives a good estimation of the clay content in Oxisols. However, the factor 2.5, based on the results of this study, appears slightly low.
7. Mineralogical composition of the different soils is strongly influenced by the parent material.
8. Heavy minerals may be fine-grained and are commonly found in the clay fraction.
9. For the soils investigated almost all of the properties of the oxic horizons meet the definitions set forth by the Soil Survey Staff, USDA.

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